LOAD CARRYING CAPACITY OF SKIRTED FOUNDATION ON SAND

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

CIVIL ENGINEERING
(GEOTECHNICAL ENGINEERING)

By

SungyaniTripathy

Roll no-211ce1234

Under the guidance of
Prof. S. P. Singh

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Dedicated to my beloved father, mother and brother for their love, affection and patience during my study

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CERTIFICATE

This is to certify that the thesis entitled "**Load carrying capacity of skirted foundation on sand**" being submitted by SUNGYANI TRIPATHYtowards the fulfilment of the requirement for the degree of Master of Technology in Geotechnical Engineering at Department of Civil Engineering, NIT Rourkela is a record of bonfire work carried out by her under my guidance and supervision.

The results presented in the thesis have not been submitted elsewhere for the award of any degree.

Prof. S.P. Singh
Department of Civil Engineering
NIT, Rourkela

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With the deepest sense of gratitude let me express my hearty indebtedness to my revered guide **Dr. S. P. Singh**, Professor of Civil Engineering, National Institute of Technology, Rourkela for kindly providing me an opportunity to work under his supervision and guidance. His keen interest, invaluable active guidance, immense help, unfailing aspirations, wholehearted cooperation and faithful discussions throughout the semester are embodied in this dissertation.

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SungyaniTripathy

M Tech (Geotechnical Engineering)
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CONTENTS

ABSTRACT

Skirted foundations are considered to be a viable foundation for a variety of offshore applications. Skirted foundations are used widely offshore, either as a single foundation system for gravity based structures or as discrete foundation units at the corners of jacket structures and tension leg platforms. Skirted foundations used in structures and facilities for the oil and gas industry are gradually replacing piled foundations. These foundations lead to cost savings through reduction in materials and in time required for installation. Structural skirts hold good as an alternative method of improving the bearing capacity and reducing the settlement of footing resting on soil. Structural skirts have been used for a considerable period to increase the effective depth of the foundations in marine and other situations where water scour is a major problem. In comparison to a surface foundation, the skirt transfers the load to deeper, typically stronger, soil, thus mobilizing higher bearing capacity.

The effects of skirt length on bearing capacity were already investigated and reported in many literatures. Skirted footing capacity for combined (vertical, horizontal and moment) loads has been studied by several researchers using both numerical and physical modelling. Surface pier and skirted footings embedded in sand having different relative densities were studied and it was reported that the skirted foundations exhibit bearing capacity and settlement values closer to pier foundations. Many researchers have already conducted various vertical loading tests on square footing and concluded that this type of reinforcement increases the bearing capacity, reduces the settlement, and modifies the load settlement behaviour.

This thesis presents experimental data from a series of investigations to determine the vertical load and horizontal load carrying capacity of the skirted foundations at different skirt length to diameter ratio and at different relative densities. The main aim of the vertical and horizontal load test was to determine the bearing capacity and the lateral stability of the

skirted foundation. Model footings of40mm, 60mm, and 100mm were selected for the test at relative density of 30%, 45%, 60%, 75%, and 90% respectively. However the horizontal load test has carried out with only 60mm diameter footing at the above mentioned relative densities and skirt ratios. Tests were conducted for both smooth and rough skirt footings.

Smooth skirted foundations exhibited lesser bearing capacity and settlement values at failure than the rough skirted foundations at similar conditions. The enhancement in bearing capacity of skirted foundations occurred both with the increase in skirt depth and relative density of sand. The ultimate bearing capacity was found to increase with the size of the footing, the length of skirts and the relative density of sand. The failure strain is found to increase with the size of the footings and skirt length but decreases with increase in relative density of sand bed. In horizontal loading test at higher relative density the stress reaches to a peak value at low strain and sudden failure occurs. But at lower relative density the peak stress occurs at relatively high strain.

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Nomenclature

D= Diameter of footing

L= Length of skirt footing

γ = unit weight of the soil

Nq and Nγ= Bearing capacity factors

qult= Ultimate bearing capacity

Φ = Angle of internal friction

C= Cohesion

BCR= Bearing capacity ratio

Bs= Skirt thickness

Df= Depth of footing

Dfs= Depth to the footing base below ground level

Ds = Depth to the lower edge of the skirt below the footing base

FS_ = skirt factor

RD= Relative density of soil

R= Roughness of footing

S= Smoothness of footing

D= Completed experiment

CHAPTER-1
INTRODUCTION

INTRODUCTION

Geotechnical engineers are in search of an alternative method for improving the bearing capacity and reducing thesettlement of footing resting on soil. Though a variety ofmethods of soil stabilization are known and well-developed,they can be prohibitively expensive and restricted by the siteconditions. In some situations they are difficult to apply toexisting foundations. In this case, structural skirts hold good as an alternative method of improving the bearingcapacity and reducing the settlement of footing resting on soil.Structural skirts have been used for a considerable period toincrease the effective depth of the foundations in marine andother situations where water scour is a major problem. Thismethod of bearing capacity improvement does not require anyexcavation of the soil and is also not restricted by the presence ofa high ground water table. Skirts provided with foundations, form an enclosure in which soil is strictly confined and acts as a soil plug to transfersuper-structure load to soil. Skirted foundations have been extensively used for offshore structures like wind turbine due to easy installation compared to deep foundation. Shallow skirted foundations have been used in structures for oil, gas industry. An internal arrangement of skirts or stiffeners is provided to increase the stiffness of the foundation system. It is believed that the vertical skirts improve the foundation capacity by 'trapping' the soil beneath the raft and between the skirts so that applied soil is transferred to the soil at the skirt tips. Skirt foundations have a wide variety of functions such as control of settlement during service life, less impact to environments during operation at installation site.Skirted foundations are used to satisfy bearing capacity requirement, and to minimize the embedment depth and dimensions of the foundation. Vertical loading due to the self -weight of installation (eg. Jacket structure, wind turbine) is improved as soft surface soils are confined within the skirt and the foundation loads are transferred down to harder underlying layers; Horizontal load capacity is improved by the skirt resisting lateral sliding.

1.1 AIM AND OBJECTIVE

Shallow foundations are now viable foundation for both offshore and surface areas.Skirted foundations are the shallow foundations which satisfy bearing capacity requirement, and to minimize the embedment depth and dimensions of the foundation. The main purpose of the research work is to investigate the:

- Effect of area ratio and skirt length on vertical load carrying capacity
- Effect of surface roughness of skirts and relative density of sand bed on vertical load carrying capacity
- Effect of size of the footingon vertical load carrying capacity
- Effect of area ratio and skirt length on horizontal load carrying capacity

1.2 ORGANIZATION OF THE THESIS

The thesis has been arranged in five chapters as discussed below:

Chapter 1: A brief introduction of the topic is presented

Chapter 2: A detailed literature review is described.

Chapter 3: The experimental work and methodology adopted

Chapter 4: Results and discussion of both vertical and horizontal load in skirted foundation.

Chapter 5: The conclusions and scope for the future study are presented.

CHAPTER-2

LITERATURE STUDY

LITERATURE STUDY

2.1 INTRODUCTION

Shallow foundations for offshore structures include skirts to satisfy bearing capacity requirement and to provide the additional horizontal resistance required by offshore environmental loading. In comparison to a surface foundation, the skirt transfers the load to deeper, typically stronger, soil, thus mobilising higher bearing capacity.Skirted foundation has been used as support for large fixed substructures or anchors for floating structures in offshore hydrocarbon development projects. In recent years skirt suction foundations are applicable to bridge substructures installed in waters. Although a number of theories are available to predict the bearing capacity of shallow footings with reasonable accuracy and it seems there is a convergent prediction of bearing capacity. Unlike this till date the estimation of bearing capacity of skirted foundations are best semi empirical formulations. Researchers have tried to estimate the bearing capacity of skirted footings and parameters influencing it, using numerical analysis, theoretical formulation, model test and prototype field tests. These are discussed in the following sections.

2.2 APLICATIONS OF SKIRTED FOUNDATION

Skirted foundation is mainly used in offshore structures. The main applications of skirted foundation are:

- Jack up unit structure
- Wind turbine foundation
- Oil and petrol gas plant
- Tension leg platforms
- Bridge foundation

Fig.2.1. a. Troll platform installed ’95 Fig.2.1.b. jack up unit structure

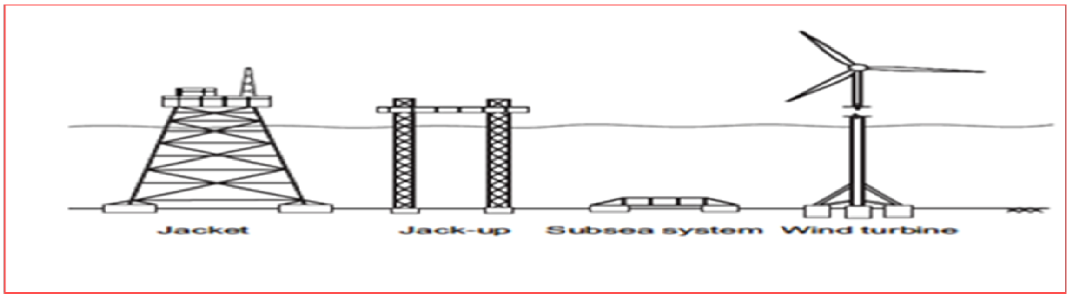

Fig.2.1. c. Skirted foundation used in jacket, jack-up, subsea system and wind turbine

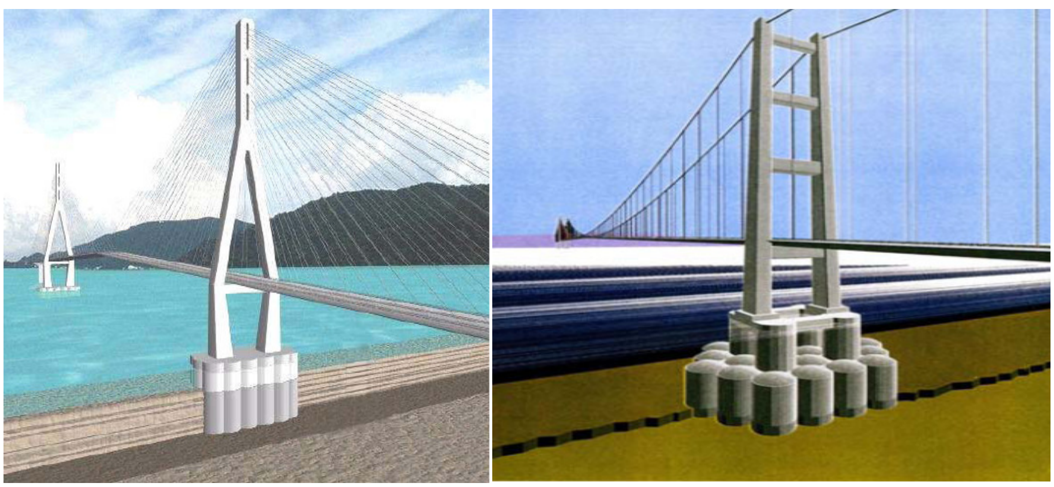

Fig.2.1.d.Application of skirt suction foundation to bridge substructure

2.3BEARING CAPACITY OF SHALLOW FOUNDATIONS

Theoretical and experimental research has been carried out for more than eighty years to resolve rigorously the bearing capacity of shallow foundations on sand. There are available solutions for flat strip and flat circular footings as well as for conical footings, but not yet for skirted footings. Since a flat footing is a particular case of a skirted footing with no skirt, the study of flat footings is a natural starting point for the subsequent study of skirted footings. By means of a combination of lower and upper bound theorems and empiricism Terzaghi (1943) developed a general bearing capacity formulation subjected to central vertical loading. Footing of width B and length L (A = BL) on a soil with angle of friction Φ, cohesion c, and surcharge γ the bearing capacity q_{ult} can be written

as:

$$q_{\mathrm{ult}} = \frac{Q_{\mathrm{ult}}}{BL} = cN_c + \tfrac{1}{2}\ \gamma_t B N_\gamma + \gamma_t D_f N_q$$

Where

q_{ult}= ultimate bearing capacity factors

γ= unit weight of soil

D_f=foundation depth

B = foundation width

Nq and Nγ are the bearing capacity factors.

These bearing capacity factors are dependent on the friction angle of the soil and increase with the value of friction angle. For sand the ultimate bearing capacity equation

$$q_{\mathrm{ult}} = \frac{Q_{\mathrm{ult}}}{BL} = \tfrac{1}{2}\ \gamma_t B N_\gamma + \gamma_t D_f N_q$$

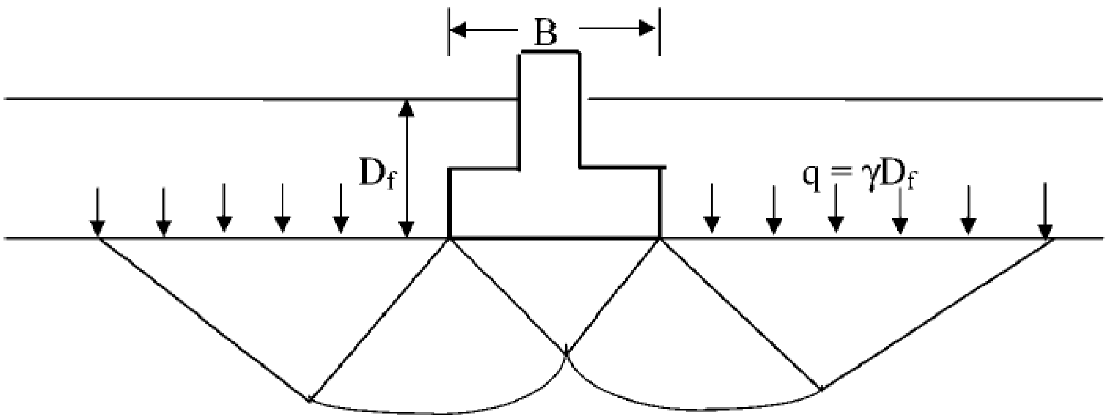

Figure 2.2.Bearing capacity failure mechanism in soil under a rough rigid continuous foundation subjected to vertical central load proposed by Terzaghi (1943)

Hansen (1970) and Vesic (1973) also proposed additional correctionfactors for shape, depth and load inclination.

2.4 FAILURE MECHANISM OF SHALLOW FOOTINGS

Experimental evidence in the literature indicates that failure mechanisms can be categorized as general shear, local shear and punching shear.

2.4.1 General Shear Failure

General shear failure involvestotal rupture of the underlying soil. There is a continuous shear failureof the soil (solid lines) from below the footing to the ground surface. When theload is plotted versus settlement of the footing, there is a distinct load at whichthe foundation fails (solid circle), and this is designated Q_{ult}. The value of Q_{ult}divided by the width (B) and length (L) of the footing is considered to be the‘‘ultimate bearing capacity’’ (q_{ult}) of the footing. The ultimate bearing capacityhas been defined as the bearing stress that causes a sudden catastrophic failurewith pronounced peak in P – Δ curvefoundation. General shear failure ruptures andpushes up the soil on both sides of the footing. For actual failures it the field,the soil is often pushed up on only one side of the footing with subsequent ttilting of the structure.This type of failure is seen in dense and stiff soil. The following are some characteristics of general shear failure.Dense or stiff soil that undergoes low compressibility experiences this failure.Continuous bulging of shear mass adjacent to footing is visible.The length of disturbance beyond the edge of footing is large.State of plastic equilibrium is reached initially at the footing edge and spreads gradually downwards and outwards.General shear failure is accompanied by low strain (<5%) in a soil with considerable Φ (Φ>36°) and having high relative density (ID > 70%).

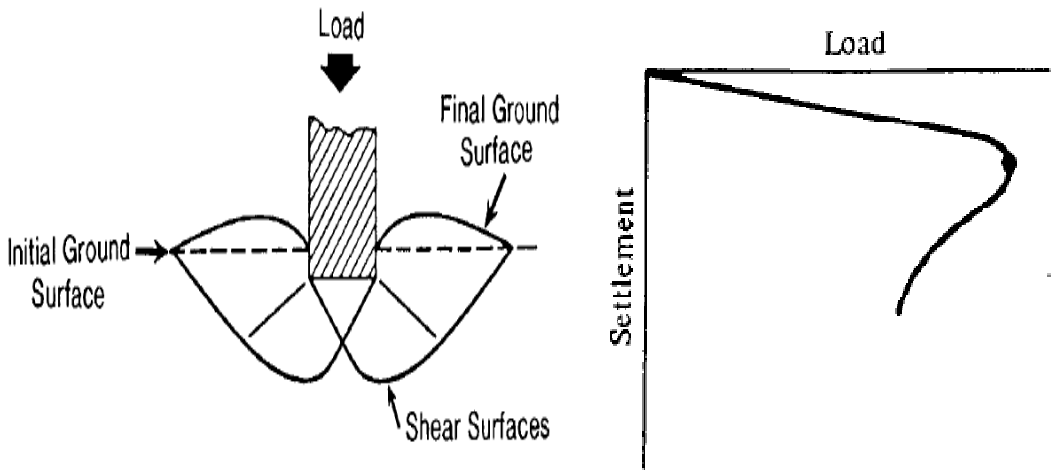

Figure 2.4(a).General shear foundation failure for soil in a dense or hard state.

2.4.2 Punching Shear Failure

Punching shear failure does not develop the distinct shear surfaces associated with a general shear failure. For punching shear, the soil outside the loaded area remains relatively uninvolved and there is minimal movement of soil on both sides of the footing. The process of deformation of the footing involves compression of soil directly below the footing as well as the vertical shearing of soil around the footing perimeter. The load settlement curve does not have a dramatic break, and for punching shear, the bearing capacity is often defined as the first major nonlinearity in the load-settlement curve (open circle). A punching shear failure occurs for soils that are in a loose or soft state. Failure is characterised by large settlement.

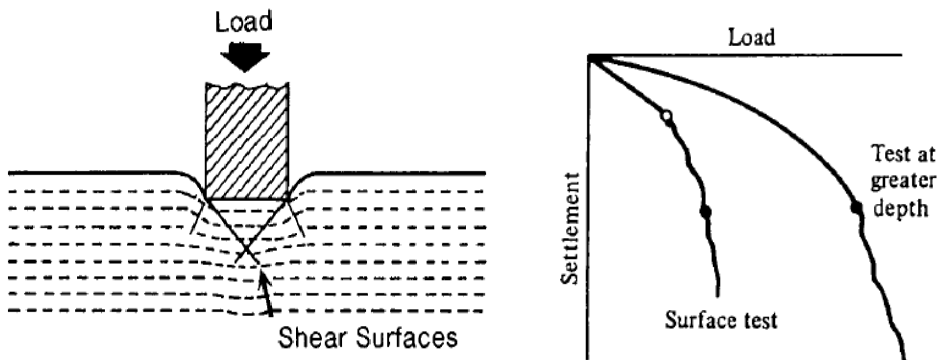

Figure2.4(b). Punching shear foundation failure for soil in a loose or soft state.

2.4.3 Local Shear Failure

Local shear failureinvolves rupture of the soil only immediately below the footing. There is soil bulging on both sides of the footing, but the bulging is not as significant as in general shear. Local shear failure can be considered as a transitional phase between general shear and punching shear. Because of the transitional nature of local shear failure, the bearing capacity could be defined as the first major nonlinearity in the load-settlement curve (open circle) or at the point where the settlement rapidly increases (solid circle). A local shear failure occurs for soils that have a medium density or firm state. The documented cases of bearing capacity failures indicate that usually the following three factors (separately or in combination) are the cause of the failure. This type of failure is seen in relatively loose and soft soil. The following are some characteristics of general shear failure. A significant compression of soil below the footing and partial development of plastic equilibrium is observed. Failure is not sudden and there is no tilting of footing. Failure surface does not reach the ground surface and slight bulging of soil around the footing is observed. Failure surface is not well defined. Failure is characterized by considerable settlement. Well defined peak is absent in P – Δ curve. Local shear failure is accompanied by large strain (> 10 to 20%) in a soil with considerably low Φ ($\Phi<28^{o}$) and having low relative density (ID > 20%).

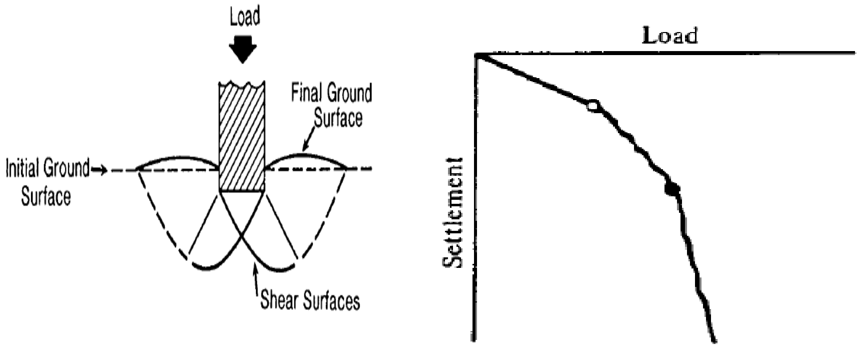

Figure 2.4(c).Local shear foundation failure for soil in a loose or soft state.

2.5 BEARING CAPACITY OF SKIRT FOUNDATIONS

For shallow strip foundation with structural skirts resting on dense sand and subjectedto central vertical load (Figure 2.6), following modifications to the general ultimate bearingcapacity equation has been proposed.

(i) For all situations, the soil above the lower edges of the skirts should be treated as a surcharge, in a manner similar to that proposed for shallow strip foundations by Terzaghi (1943)

(ii) To determine the ultimate bearing capacity of a shallow strip foundation with structural skirts, a skirt factor ($F\gamma$) should be introduced into the second part of the general equation, to account for all the characteristics of the structural skirts, the soil, the foundation and the loading, which influence the ultimate bearing capacity of the foundation. No factor is included in the first part of the general equation because the effect of the skirt can be accounted for by the skirt depth. Thus the modified ultimate bearing capacity equation may be written as:

$$q_{\text{ult}} = \gamma(D_{fs} + D_s)N_q + 1/2\ B'\gamma N_\gamma F_\gamma$$

Where

F_γ =Skirt factor

D_{fs} = Depth to foundation base below ground level

D_s = Depth to the lower edge of the skirt below the foundation base

B□= Total foundation width with skirts($B+2B_s$)

B_s= Skirt thickness

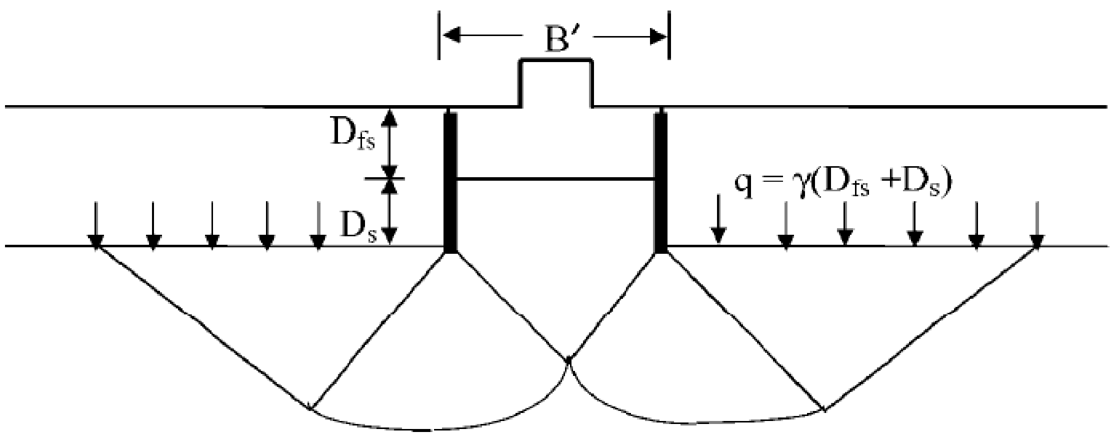

Figure2.5.Bearing capacity failure mechanism in soil under continuous foundation with structural skirt subjected to vertical central load (Based on Terzaghi (1943) assumptions)

The literature study for skirted foundations can be broadly classified into four categories:

a. Numerical and Physical analysis
b. Theoretical analysis
c. Model test
d. Prototype test

2.5.1 NUMERICAL AND PHYSICAL ANALYSIS

Susan Gourvenec and Mark. F. Randolph (2012) used the finite-element analyses to quantify the immediate and time-dependent response of circular skirted foundations to uniaxial vertical loading. Foundations with frictionless and fully rough skirt-soil interfaces with varying ratio of embedment depth to foundation diameter are considered and the results are compared with those for surface foundations. It shows that both skirt-soil interface roughness and embedment ratio have a significant effect on the consolidation response.

M. F. Bransby, and G.-J. Yun (2009) conducted a series of plane-strain finite element analyses to investigate directly how the skirt geometry affects the un-drained strip foundation capacity under combined horizontal–moment loading and the mechanisms occurring at failure. It shows that deformation of the soil between external skirts can lead to significantly less foundation capacity than that of an equivalent solid embedded foundation. The specific geometry of the foundation must be considered in design. In addition, the failure envelopes for skirted foundations with different embedment ratios differed significantly. According to them, the significant increase in foundation bearing capacity may be achieved by adding an intermediate skirt to the foundation, which results in a foundation capacity that is almost equal to that of a solid embedded foundation.

L Kellezi, G Kudsk, H Hofstede (2008) carried out conventional and numerical, finite element soil foundation interaction modeling for the world's largest three-leg jack-up, skirted footings resting on layered soil conditions consisting of sand overlying clay with varying strength. The footings were subjected to general combined vertical V, horizontal H and moment M loadings. Differences between the yield capacities calculated from the PLAXIS 2D and 3D, a design yield envelope was proposed and some experience and recommendations for offshore foundation design applicable to similar soil conditions are drawn.

G. Yunand and M.F.Bransby (2007) presented the vertical bearing capacity of skirted foundation on normally consolidated un-drained soil using numerical and physical analysis. Finite element analysis had been carried out to investigate the vertical bearing capacity of foundations with different geometrics for various embedment ratios. Accordingly upper bound plasticity analysis highlighted the mechanistic reasons for the varying response and allowed examination of the effect of changing skirt influence friction. They have showed that skirted foundation capacity under vertical load is considered normally as if the foundation is rigid with an embedment depth equal to skirt depth. The results from the design methods deduced from the analyses and compared to the results of centrifuge model tests of skirted foundation in normally consolidated clay.

Yun and Bransby(2003)made a comparative study between load–displacement responsefrom centrifuge test data and finite element results of skirted circular footings of different skirt roughness and skirt depth up to five times the footing diameter. They also conducted a series of centrifuge model tests on a skirted footing subjected to vertical load, moment, and horizontal load; and proved that the skirted foundation increased the horizontal capacity to about 3–4 times that of the un-skirted foundation. They suggested that the failure mode changed to rotational mode instead of sliding mechanism**.**

Y. Hu,M. F. Randolph, and P. G. Watson(2002) studied theCircular skirted offshore foundations on non-homogeneous soil by numerically, analytically, and physically, with the offshore sediment simulated as a cohesive soil with strength increasing linearly with depth. In the numerical analysis, the h-adaptive FEM is adopted to provide an optimal mesh, in which a strain-super convergent patch recovery error estimator and mesh refinement with subdivision concept are used. The bearing capacity of the foundations is studied with the degree of non-homogeneity (kD/s uo) of soil up to 30, different skirt roughness and skirt depthup to five times the foundation diameter (i.e., $D_f/D = 5$), FEM and extended upper-bound method. In the foundation large penetration study, circular skirted foundations penetrating into normally consolidated and over consolidated soils are tested physically in the centrifuge and analyzed numerically using the h-adaptive re-meshing and interpolation technique with small strain method for soil large deformation analysis. The load-displacement responses from centrifuge test data and finite-element results are compared.

Bransby and Randolph (1997) studied the behavior of skirted strip footings and circular footings subject to combined vertical, horizontal and moment loading using finite element and plasticity analysis of equivalent surface foundations. The shape of the yield locus for the two foundation geometries was found to be similar but the pure vertical, moment and horizontal capacities varied with the footing shape and soil strength profile.

.Bransby and Randolph(1998) proved that vertical and horizontal capacities are affected bythe footing shape and the soil strength profile using finite element and plasticity analysis.

Bell(1991)has explained shallow offshore foundations achieve their stability through the foundation bearing on the seabed and it can idealized as large circular footings subjected to Vertical, horizontal and moment loading. He has analyses a small strain linear- elastic perfectly plastic finite element program to solve the combined loading. The 20-node quadratic strain has adopted for all the derivation

2.5.2 TEORITICAL ANALYSIS

M. Y. AL-AghbarI and Y. E-A.Mohamedzein (2004) conducted a series of tests on foundation models and study the factors that affect the bearing capacity of foundations with skirts. They studied several factors including foundation base friction, skirt depth, skirt side roughness, skirt stiffness and soil compressibility. The results obtained from the proposed equation were compared with the results obtained from Terzaghi, Meyerhof, Hansen and Vesic bearing capacity equations for foundations without skirt.

Villalobos (2007) presentedthe experimental results of scale skirted shallow foundations in sand under monotonic vertical loading. The investigation included different skirt lengths, mineralogy and density of the sand deposits. The bearing capacity formulation was used in the analysis of failure. Axial symmetric bearing capacity factors for flat footings were used. Byrne(2002)has used the shallow inverted buckets as foundations, installed by suction, in place of the piles. These foundations lead to cost savings through reduction in materials and in time required for installation. He presents experimental data from a comprehensive series of investigations aimed to determining the important mechanisms to consider in the design of these shallow foundations for dense sand. The long term loading behavior (e.g. wind and current) was investigated by conducting three degree of freedom loading {V:M/2R:H} tests on a foundation embedded in dry sand. The results were interpreted through existing work-hardening plasticity theories. The analysis of the data has suggested a number of improved modeling features. The main feature of the cyclic loading was that a 'pseudo-random' load history (based on the 'NewWave' theory) was used to represent realistic loading paths. Under combined-load cyclic conditions the results indicated that conventional plasticity theory would not provide a sufficient description of response. A new theory, termed 'continuous hyper plasticity' was used, reproducing the results with impressive accuracy.

Martin(1994) has explained the behavior of circular footings on cohesive soil under conditions of combined vertical, horizontal and moment(V,H,M) loading. He has conducted a physical model test, involving combined loading of circular footings on reconstituted speswhite kaolin. The results are interpreted to give empirical expressions for the combined load yield surface in V:H:M space and a suitable flow rule to allow prediction of the corresponding footing displacement during yielding.

2.5.3 MODEL TEST

H. T. Eid (2012) carried out physical model testing on much smaller scale. Surface, pier, and skirted square foundations resting on sand with different shear strength properties were utilized in the analysis. Effects of foundation size, shear strength of sand, and skirt depth on bearing capacity and settlement of skirted foundations were assessed. The results of this study revealed that skirted foundations exhibit bearing capacity and settlement values that are close, but not equal, to those of pier foundations of the same width and depth. The enhancement in bearing capacity of shallow foundation increases with increasing skirt depth and decreasing relative density of sand. Settlement reduction may exceed a value of 70% in case of having skirt depth to foundation width ratio of 2.0.

Amr Z. El Wakil(2010)performed twelve loading tests on small scale circular skirted footing and subjected to lateral loads. The effects of skirt length and the relative density of sand on the performance of the footing were investigated through laboratory testing program. Also a comparative experimental study between ultimate horizontal loads attained by skirted and un-skirted footings with the same properties was conducted. From the laboratory tests it was found that the skirts changed the failure mode of circular shallow footings from sliding mechanism into rotational mechanism. Also the skirts attached to footings increased appreciably the ultimate horizontal capacity of shallow footings.

Wang et al. (2006) investigate the experimental response of suction bucket foundation in fine sand layer under horizontal dynamic loading has been carried out. The developments of settlement and excess pore pressure of sand foundation have been carried out. It is observed that the sand surrounding the bucket softens or even liquefies at the first stage if the loading amplitude is over a critical value, at later stage, the bucket settles and the sand layer consolidates gradually. With the solidification of the liquefied sand layer and the settlement of the bucket, the movement of the sand layer and the bucket reach a stable state.

2.5.4 PROTOTYPE TEST

Hofstede etal.(2003)carried out the foundation engineering assessment for the world's largest jack-up rig installed offshore Norway. Based on the site survey and soil investigation data the soil conditions vary across the site and consist of bedrock overlie by very soft silt / clay and a shallow layer of seabed sand. From the conventional and finite element analyses an engineering solution comprising construction of sand banks was proposed. The final geometry of the banks is determined based on the three dimensional (3D) finite element (FE) integrated jack-up structure skirted spud. Soil interaction modelling revealed that during the rig installation / preloading and storm loading the structural forces fall within the accepted limits. The rig was successfully installed and upgraded verifying the engineering predictions.

Martin et al.(2001) compared the varying length of the skirt (L) with the diameter (D) of the foundation as well as varying the mineralogy and density of the sand deposits. Results from vertical bearing capacity tests are presented and compared with simple theoretical expressions based on standard bearing capacity formulae.

2.6 SCOPE OF THE PRESENT WORK

A good number of research papers are available in the literature, but they are not enough and coherent. In addition to this, the effect of increase in dia., skirt roughness on load carrying capacity has not been subject of investigation by researchers. Present work aims in evaluating the

I. Vertical load carrying capacity of smooth, roughskirt footings embedded in sand beds of different relative density and with different skirt lengths.
II. Effect of footing size on vertical load carrying capacity of skirted foundations.
III. Horizontal load carrying capacity of skirt footings embedded in sand beds of different relative density and with different skirt lengths.

CHAPTER-3

EXPERIMENTAL WORK AND METHODOLOGY

EXPERIMENTAL WORK AND METHODOLOGY

3.1 INTRODUCTION

Literature review shows that researchers have tried to predict the bearing capacity of skirted foundations by adopting numerical and physical analysis, experimental and theoretical analysis, model tests, and prototype tests. However, till date the prediction of bearing capacity of skirted foundations are based on semi-empirical approach. The main benefit of the experimental analysis is that it can be extended to prototype structures. Trends and relations developed between the bearing capacity ratio and skirt length; relative density and angle of internal friction can be extrapolated to the prototype structures. A number of parameters which influences the bearing capacity can be controlled in laboratory model tests. Details of material used, sample preparation and testing procedure adopted have been outlined in this chapter.

3.2 MATERIALS AND TESTING FACILITIES

3.2.1 Sand specimen

The sand was brought from nearby river of Rourkela and was oven dried for one day. Then it was sieved in 2mm and 0.425 mm sieve. The sand which are passed in 2mm and retained in 0.425mm sieve was taken for the research work.The specific gravity of the soil particles was measured according to the ASTM standard and has an average value of 2.61. The maximum and minimum dry unit weight of sand is 16.25 and 13.75 kN/$m^3$and corresponding values of minimum and maximum void ratios are 0.606 and 0.897 respectively. The particle size distribution was determined using dry sieve method. The mean particle size (D_{50}), the uniformity coefficient (C_u) and coefficient of curvature (C_c) for the sand was 0.75, 2, and

1.01 respectively. The model footing loading tests were conducted on sand beds prepared with average unit weight of 14.42, 14.8, 15.2, 15.5 and 16 kN/m^3 representing loose, medium, dense and very dense conditions respectively. The relative densities of the sand beds corresponding to the above mentioned densities are 30, 45, 60, 75, and 90 respectively and the estimated internal friction angle are 33.2°, 35. 22˚,37.5˚, 39.4°, and 43.1˚ respectively.

3.2.2 Soil bin and model footings

The experimental set-upconsists of two main elements: the soil bin and the loading system. The cylindrical soil bin was made up of rigid steel sheets with inside diameter of 45 cm and height of 60 cm. The model footing was a mild steel circular footing of diameter (D) equal to 40mm, 60mm and 100mm of thickness 10mm. Skirts are made from mild steel sheets of 2mm thick and are welded firmly and accurately to the footings. The skirt lengths (L) to the footing diameter L/D values of 0.4, 0.6, 1.2, 1.5, and 2 were maintainedfor 60mm dia. Both smooth and rough conditions have been tested. A rough condition was achieved by fixing a thin layer of sand to the outer, inner of the skirt and the base of the footing. Vertical load test have also conducted in both smooth and rough embedded foundation.

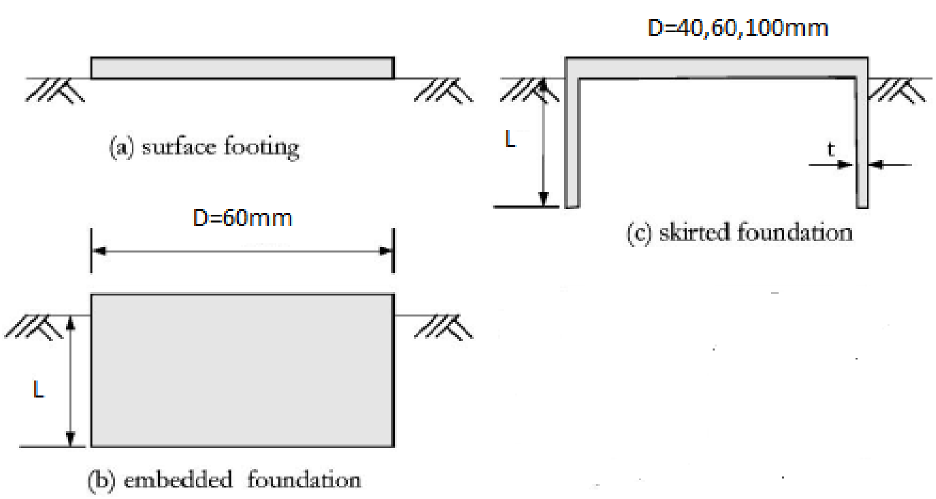

Figure3.1 Geometry of footings studied

Figure 3.2 Skirt length ratio of 60mm dia.

3.3 TEST PROGRAM AND METHODOLOGY

The test conducted for vertical and horizontal load test details are given in Table 3.1.

3.3.1 Experimental set up and procedure for vertical load test

The sand was formed in the soil bin in layers each 50mm thickness. To ensure homogeneity of sand formation, a calculated weight of sand with an accuracy of 0.001kN was formed into a certain volume of sand by compaction to give specific relative densities. For higher relative densities 75 and 90 the soil bin was vibrated in the vibrating table with the footing embedded in it with a top plate on it till the required density was achieved. The bin was then placed on the strain controlled loading platform without disturbing the density of the soil. The load was transferred to the footing through a ball which was placed between the footing and the proving ring. Such an arrangement produced a hinge, which allowed the footing to rotate freely as the underlying soil approached failure and eliminated any potential moment transfer from the loading fixture. Finally vertical load was applied at a strain rate of 1mm/minute. Dial gauge was placed on the footings to measure the vertical settlement of the footing. Ten laboratory experiments were conducted in surface footing for each relative density and smooth and rough footing conditions. Twenty five tests are conducted in smooth skirt footing and twenty five tests are conducted in rough footings. Several tests were repeated at least twice to examine the performance of the apparatus, the repeatability of the system and also to verify the consistency of test data. Very closest patterns of load-settlement relationship with the maximum difference in the results less than 5% were obtained.

Figure-3.3 Complete set-up for Vertical loading test

The vertical failure load for smooth skirted footing obtained from the load settlement curve of 40mm, 100mm, and 60mm dia. are given in the Table 3.1, Table3.2 and Table 3.3 respectively. The failure load for rough footing is given in Table 3.4. The vertical failure load for 60mm dia. smooth and rough solid cylindrical footings are given in Table 3.5 and Table 3.6.

Table 3.1 Details of Model Tests Conducted

Skirt Ratio↓	Vertical Load Test										Horizontal Load Test				
Relative Density→	30%		45%		60%		75%		90%		30%	45%	60%	75%	90%
60mm dia.	S	R	S	R	S	R	S	R	S	R					
0	D	D	D	D	D	D	D	D	D	D					
0.4	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
0.6	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1.2	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1.5	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
2	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Solid Footing (60 mm Dia.)															
0.4	D	D	D	D	D	D	D	D	D	D					
0.6	D	D	D	D	D	D	D	D	D	D					
1.2	D	D	D	D	D	D	D	D	D	D					
1.5	D	D	D	D	D	D	D	D	D	D					
2	D	D	D	D	D	D	D	D	D	D					
Skirt ratio ↓ (40mm dia.)															
0	D		D		D		D		D						
0.4	D		D		D		D		D						
0.6	D		D		D		D		D						
1.2	D		D		D		D		D						
1.5	D		D		D		D		D						
2	D		D		D		D		D						
Skirt ratio ↓ (100mm dia.)															
0	D		D		D		D		D						
0.4	D		D		D		D		D						
0.6	D		D		D		D		D						
1.2	D		D		D		D		D						
1.5	D		D		D		D		D						
2	D		D		D		D		D						

Table 3.2Vertical failure load for 40mm dia. footings

Skirt Ratio.	Vertical Failure Load (Kpa)				
	RD 30%	RD 45%	RD 60%	RD 75%	RD90%
0	*42.01*	53.2	59	68	81
0.4	*49.18*	64.03	107	198.3	309

0.6	*65*	86.3	156	240.35	405
1.2	*115.1*	149.5	198	304	666
1.5	*148.5*	192	228.3	538	882
2	*224.8*	343.35	431	736.23	968.44

Table 3.3Vertical failure load for 100 mm dia. footings

Skirt Ratio	Vertical Failure Load (kPa)				
	RD 30%	RD 45%	RD 60%	RD 75%	RD90%
0	117	130	170	189	265.01
0.4	250	285	478	655	1256
0.6	434	492	826	1000	2096
1.2	755	883	1613	2109	3336
1.5	1553.4	1794	2370	3527	5283
2	1614	1835	2509	4347	8005

Table 3.4Vertical failure load for 60mm dia. smooth footings

Skirt Ratio	Vertical Failure Load (kPa)				
	RD 30%	RD 45%	RD 60%	RD 75%	RD90%
0	52.7	59.5	66.3	78.5	95
0.4	80	142	169.01	215.05	350.3
0.6	90	151.5	177.2	323.25	654
1.2	208.3	337	425	713	1241
1.5	307.4	389	526	792.5	1970
2	370.34	622.2	759.2	1137	2444

Table 3.5 Vertical failure load for 60mm dia. rough footings

Skirt Ratio	Vertical Failure Load (kPa)				
	RD 30%	RD 45%	RD 60%	RD 75%	RD90%
0	61	77	90.6	118	150

0.4	128	162	212	315	607
0.6	150	235	290	637	859
1.2	320	420	517.4	746	1596
1.5	405	522	779	1070	2572
2	522	922.2	1130	1989	3773

Table 3.6Vertical failure load for 60mm dia. smooth solid cylindrical footings

Skirt Ratio	Vertical Failure Load (kPa)				
	RD 30%	RD 45%	RD 60%	RD 75%	RD90%
0.4	102.8	147.43	215.06	290.8	419.3
0.6	131.2	170.43	268	327.3	809
1.2	211.01	276	456.3	619	1072
1.5	379	491.6	799	1299	1863
2	677.4	776.2	1307	2100	2680

Table 3.6Vertical failure load for 60mm dia. rough solid cylindrical footings

Skirt Ratio	Vertical Failure Load (kPa)				
	RD 30%	RD 45%	RD 60%	RD 75%	RD90%
0.4	115.4	171.4	238	345	550.2
0.6	180	238	292	454	867
1.2	224.5	299	489.3	1020	1494
1.5	458	727	931.4	1555	2794
2	712	963	1871	3126	4220

3.3.2 Experimental set up and procedure for horizontal load test

To study the behaviour of horizontally loaded skirted foundationson sand, laboratory tests were conducted on a steel circular model footing of diameter (D) equal to 60 mm and ofthickness 10 mm. The skirt length (L) to the footing diameter ratios L/D were 0.4, 0.6, 1.2,1.5 and 2. The skirts have a thickness of 10mm without notch at their tips. Skirts are made from steel and welded firmly and accurately to footings. The lengths of skirts are measured after welding to the footings. Twenty five laboratory experiments are conducted on the circular footings to study the behaviour of the skirted foundations under the effect of horizontal loads. The model footings have smooth faces. The lateral loads are applied on the footing using frictionless pulley fixed to the soil bin and a flexible wire connected to the footing at one end to the shaft whose strain rate rotates clockwise. Proving ring is fixed between the footing and the one side of soil bin.

The soil bin is of rectangular size with dimensions of 600mm X 300mm and wall thickness of 20 mm. The height of the soil bin is 400 mm. The sides of the soil bin were strengthened using steel angles to prevent any lateral deformation of the side walls. It is obvious that the dimensions of the soil bin are big enough to overcome the effects of the boundary conditions on the footings response, whereas the side dimension of soil bin to the footingdiameter is 4 times, and the depth below the tallest skirt is 3 times the footing diameter.

The sand was formed in the soil bin in layers each of 50 mm thickness. To ensure homogeneity of sand formation a calculated weight of sand, with an accuracy of 0.001 kN, was formed into a certain volume of the soil bin by compaction to give the specified relative densities of 30%, 45%.Compaction was carried out manually using a rammer weighing 30Nand of 200 mm diameter. For higher densities 60%, 75% and 90%,the sand was vibrated to achieve the density. The top surface of the formed sand was levelled using sharpened straight steel plate and the model footing was then placed on the surface of the compacted sand. The horizontal failure load for smooth skirted footing obtained from the load settlement curve of 60mm dia.is given in the Table 3.7.

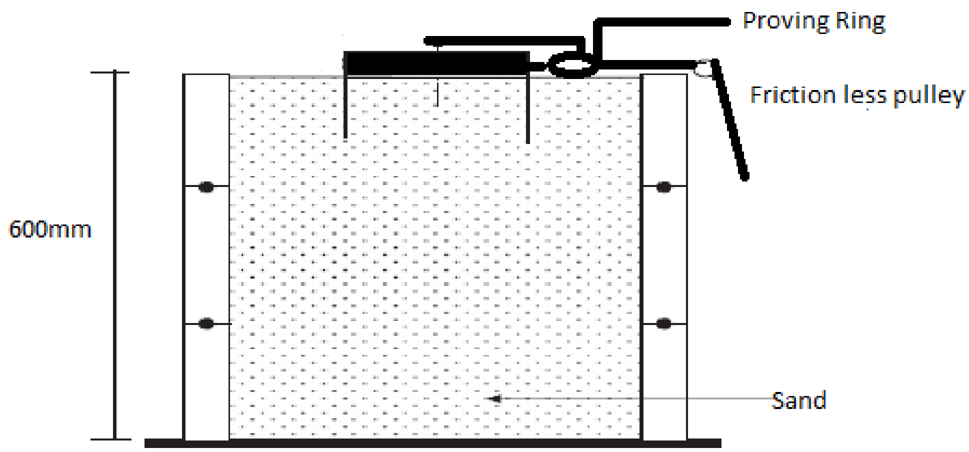

Figure-3.4 Complete set-up for Horizontal loading test

Table 3.7 Horizontal Failure Load of SkirtedFootings (60mm Dia.)

Skirt Ratio	Horrizontal Failure Load (kPa)				
	RD 30%	RD 45%	RD 60%	RD 75%	RD90%
0.4	5.600	6.630	7.876	8.861	10.619
0.6	6.411	7.862	8.861	9.845	11.321
1.2	8.400	9.353	10.830	12.798	15.279
1.5	11.814	12.798	16.791	18.213	21.659
2	13.291	15.752	21.167	26.089	35.934

CHAPTER 4

DISCUSSION ON TEST RESULTS

DISCUSSION ON TEST RESULTS

4.1 BEHAVIOUR OF SMOOTH SURFACE FOOTING

Thirty numbers of tests are conducted at different l/d ratio of 60mm dia. For accuracy many of the test is repeated twice.The variation of stress with strain for the footing without structural skirt for 60mm dia. at different relative densitiesis shown in Figure 4.1(a). Study of this figure reveals that the vertical load increases with the increase in the density. The results from the bearing capacity tests for different density further analysed and compared by using angle of internal friction and relativedensity 30, 45,60, 75 and 90%.,are used to calculate the bearing capacity factors suggested by Terzaghi (1943), Meyerhof (1963), Hansen (1970) and Vesic (1973) (Figure 4.1(b)).Martin(2005) created a software ABC from which accurate calculation of bearing capacity can be made. Bearing capacity valuesusing ABC software also included in Figure 4.1(b) under the name of Martin.The test data show that a high degree of reproducibility was achieved in the tests, which gives confidence in the preparation of the sand sample and the apparatus performance. Thus it can be concluded that the experimental results confirm the theoretical prediction and can be used asthe basis for determining the improvement to be derived from the use of a structural skirt. Fig 4.1(c) shows the general shear failure mechanism of ABC software.

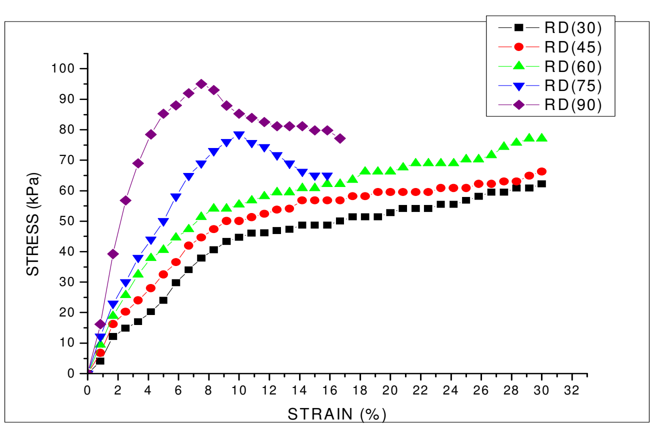

Fig.4.1(a)Stress-strain behaviour of smooth surface footing

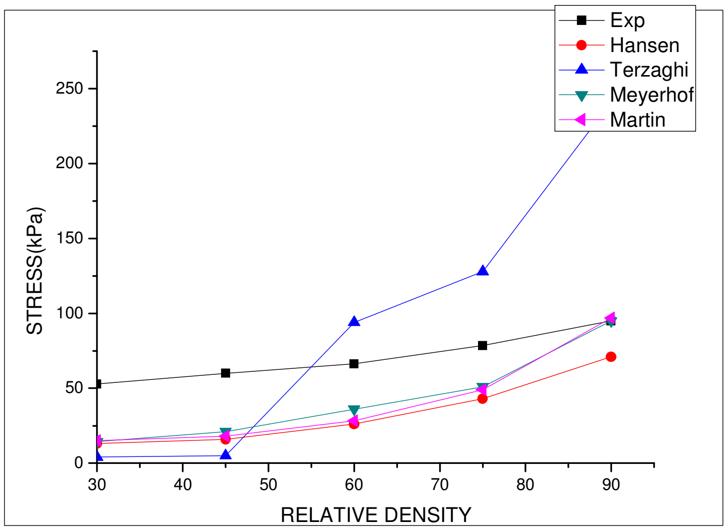

Fig.4.1(b) Comparison of experimental and predicted values of ultimate bearing capacity

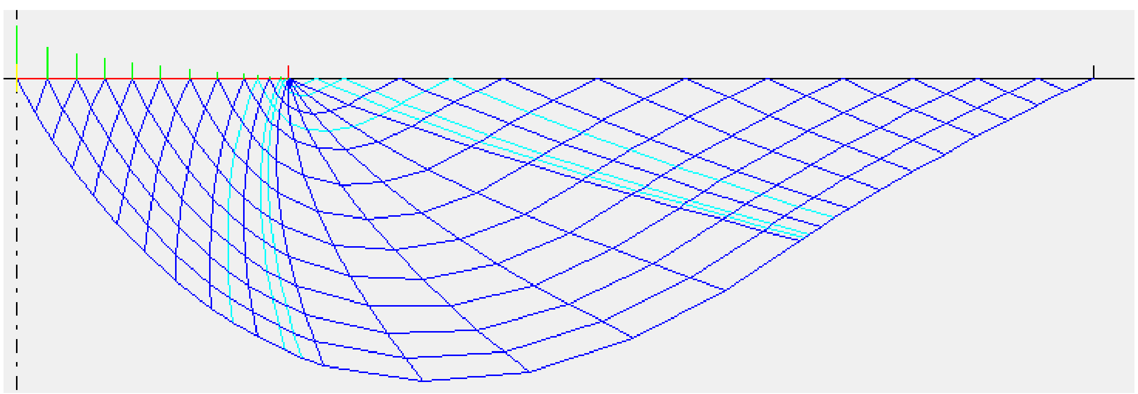

Fig.4.1(c) General shear failure mechanisms (Martin, 2005) at RD 75%

4.2 BEHAVIOUR OF SKIRTED FOOTING (VERTICAL LOADING)

4.2.1 Load-Settlement Behaviour

Typical load-settlement curves for smooth circular skirted footing with skirt ratio of 0.4, and 1.5 are shown in Fig.4.2 and 4.3respectively. Fig 4.4 and 4.5 shows the load-settlement curves for different skirt lengths with constant relative density 60% and 90% respectively.

Analysis of the experimental results revealed that inclusion of skirts improves bearing capacity of the surface foundations on sand. The improvement in magnitude increases with increasing the skirt depth as well as relative density. At higher relative density the stress reaches to a peak value at low strain and sudden failure occurs. But at lower relative density the stress continues to rise non-linearly with strain. While comparing the skirt footing with surface footing it is revealed that in skirt footing the failure stress is higher than surface footing. And in higher densities there is no sudden failure; it reaches to a peak value at relatively low strain, after that the peak the bearing value reduces gradually. To follow the failure criteria peak value has taken for higher densities and bearing values at 20% strain for footings embedded in sand beds of lower relative densities, where no definite peaks are available. Further it is noticed that the stiffness of load-settlement curves increases with either increase in skirt ratio and relative density.

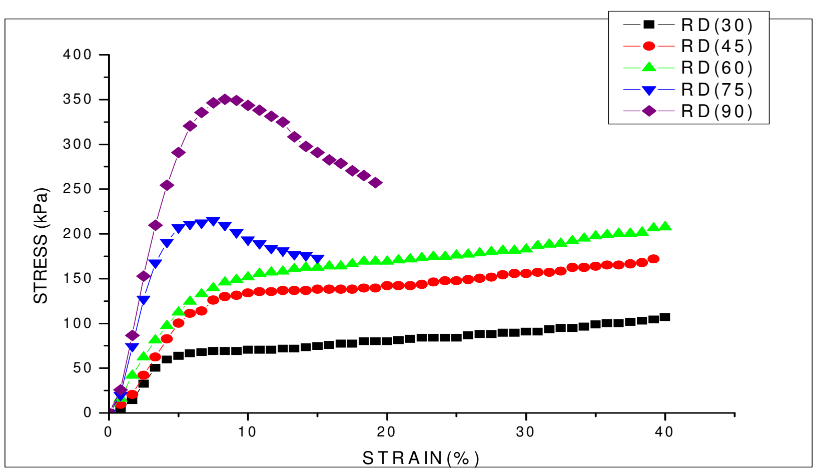

Fig.4.2Stress-strain behaviour of smooth skirted footingof 60mm dia. at L/D Ratio 0.4

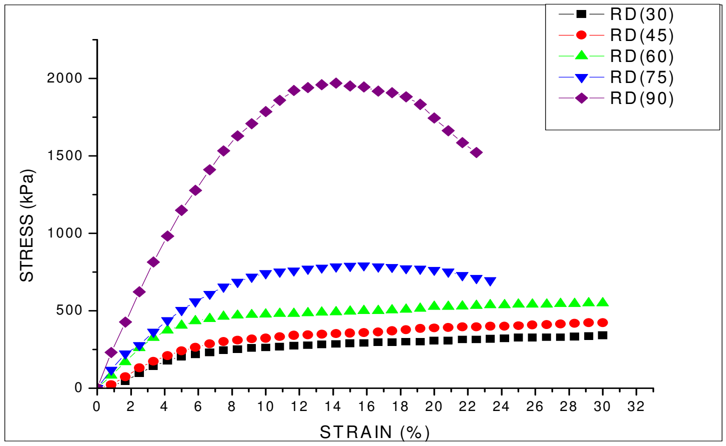

Fig.4.3Stress-strain behaviour of smooth skirted footingof 60mm dia. at L/D Ratio 1.5

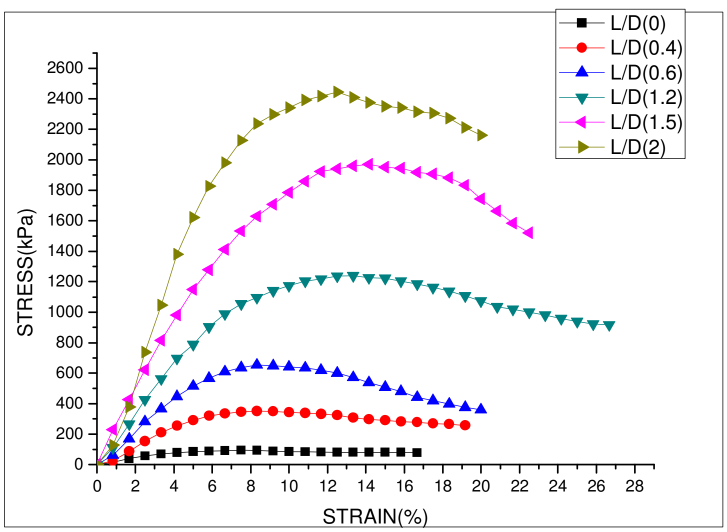

Fig. 4.4Stress-strain behaviour of smooth skirted footingof 60mm dia. at R D of 90%

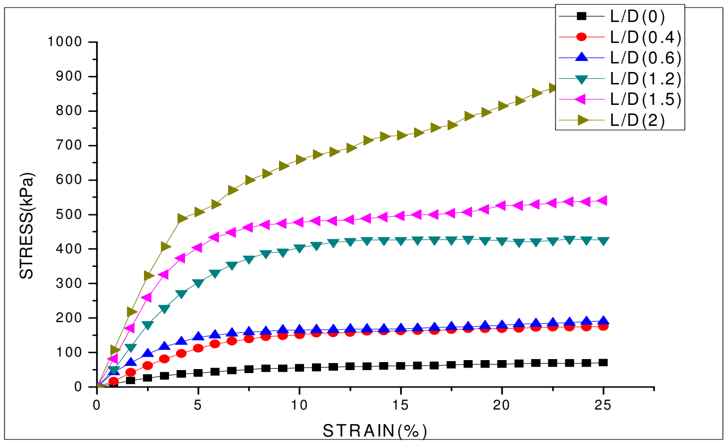

Fig.4.5Stress-strain behaviour of smooth skirted footingof 60mm dia. at R D of 60%

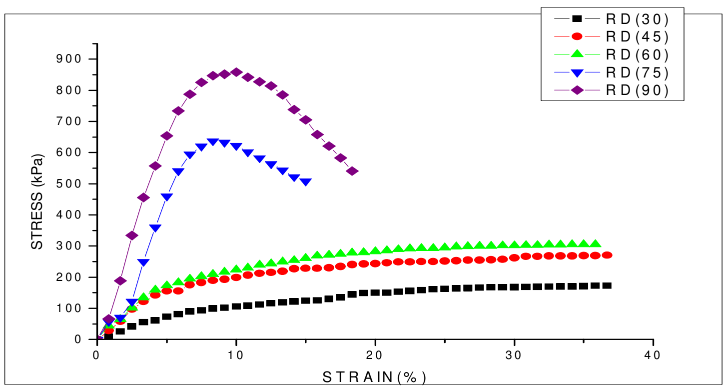

Fig.4.6Stress-strain behaviour of roughskirted footingof 60mm dia. at L/D Ratio 0.6

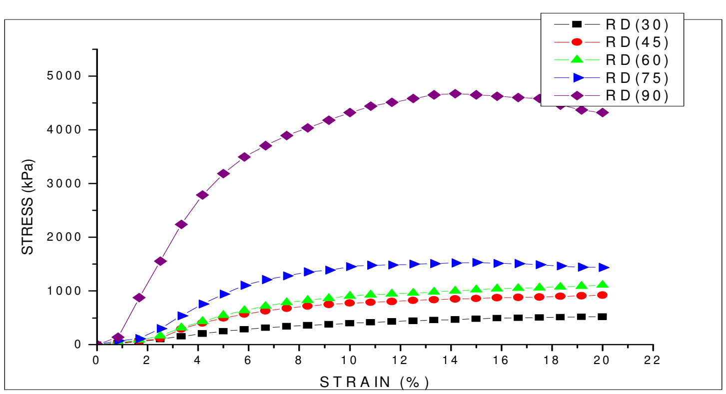

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Fig.4.7Stress-strain behaviour of roughskirted footingof 60mm dia. at L/D Ratio 2

Comparing the load settlement curve at skirt length to diameter ratio 0.6 to 2 for 60 mm dia. (figures 4.6 and 4.7), it can observe that at L/D=2 and at relative density there is no peak failure. The failure occurs like local shear failure. The failure slowly decreases and the strain also increases. This type occurs more in rough skirt foundation.For similar test conditions a rough footing registers higher failure load as well as the stiffness of load-deformation curve is also found to be more.

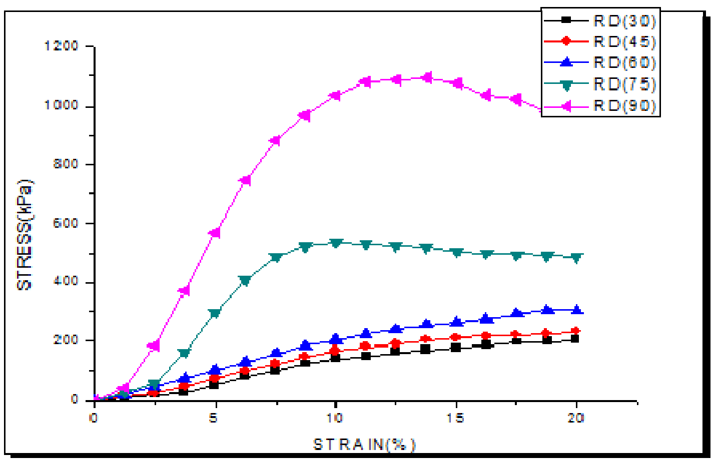


Fig.4.8Stress-strain behaviour of skirted footingof 40mm dia. at L/D Ratio 1.5

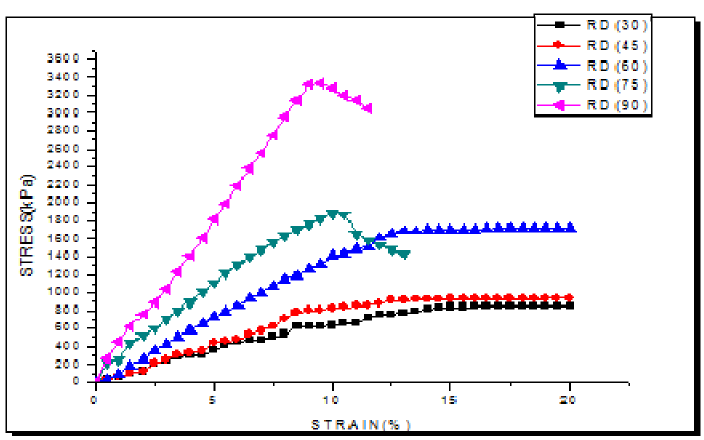


Fig.4.9Stress-strain behaviour of skirted footingof 100mm dia. at L/D Ratio 1.2

Typical load-settlement curves for 40mm dia. and 100mm dia. smooth circular surface footing are shown in Fig 4.8 and 4.9. Analysis of the experimental results revealed that change in dia. improves bearing capacity of the surface foundations. The improvement in magnitude is more with increase in dia. longer skirts as well as with higher relative density. At higher relative density at100mm the stress reaches to a peak value at low strain and sudden failure occurs. But at lower relative density the stress continues to rise non-linearly with strain. To follow the failure criteria peak value has taken for higher densities and bearing values at 20% strain for footings embedded in sand beds of lower relative densities. Further it is noticed that the stiffness of load-settlement curves increases with change in relative density increase in skirt ratio and relative density.

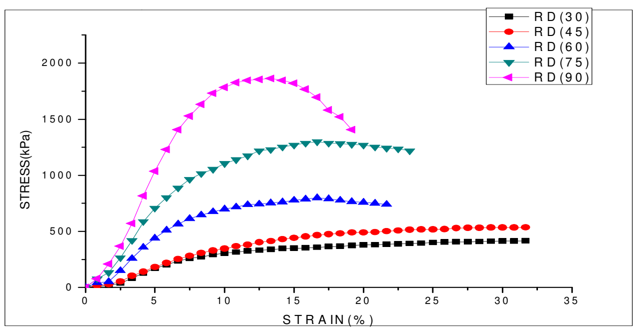


Fig.4.10Stress-strain behaviour of smooth solid cylindrical footingof 60mm dia. at L/D Ratio 1.5

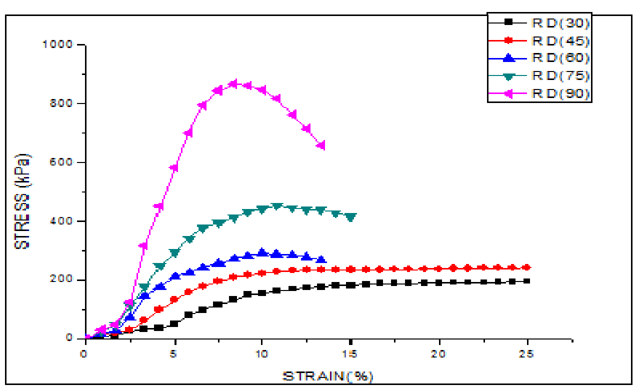


Fig.4.11Stress-strain behaviour of rough solid cylindrical footingof 60mm dia. at L/D Ratio 1.5

Effects of foundation size, shear strength of sand, and solid foundation depth on bearing capacity and settlement of the foundations were assessed. The results of this study revealed that skirted foundations exhibit bearing capacity and settlement values that are close, but not equal, to those of embedded foundations of the same width and depth. The enhancement in bearing capacity of shallow foundation increases with increasing depth and increase in relative density of sand.At relative density 60% in embedded foundation there is peak failure occurs at low strain. In case of skirted foundation there is no peak failure and the failure load taken at corresponding 20% strain.For similar test conditions a rough embedded footing registers higher failure load as well as the stiffness of load-deformation curve is also found to be more.

4.2.2Variation of bearing capacity ratio with skirt ratio

The bearing capacity ratio BCR is defined as the ratio of bearing capacity of skirt footing to bearing capacity of surface footing at any given relative density of sand bed**.** The variation of BCR is plotted against L/D ratio for footings of 60mm in smooth and rough skirt dia. has plotted in Figs. 4.12 and 4.13 respectively. Trend lines are drawn to know the relationship between them. The BCR increases with increase in skirt length almost parabolically. However the rate of increase in bearing capacity with skirt ratio is not same for footings embedded in sand of different relative densities. The increase in BCR with skirt ratio is higher for footings embedded in sand with higher relative density. So it can be concluded that the improvement of bearing capacity is a function of skirt length and also depends on the relative density of sand bed in which it is embedded. The skirt foundation acts as embedded foundation and skin friction occurs on the periphery of the foundation in which the bearing failure occurs parabolic. From the both the figures it has similarity that at higher density and at higher density the bearing capacity is 25 times and all the values are nearly equal.

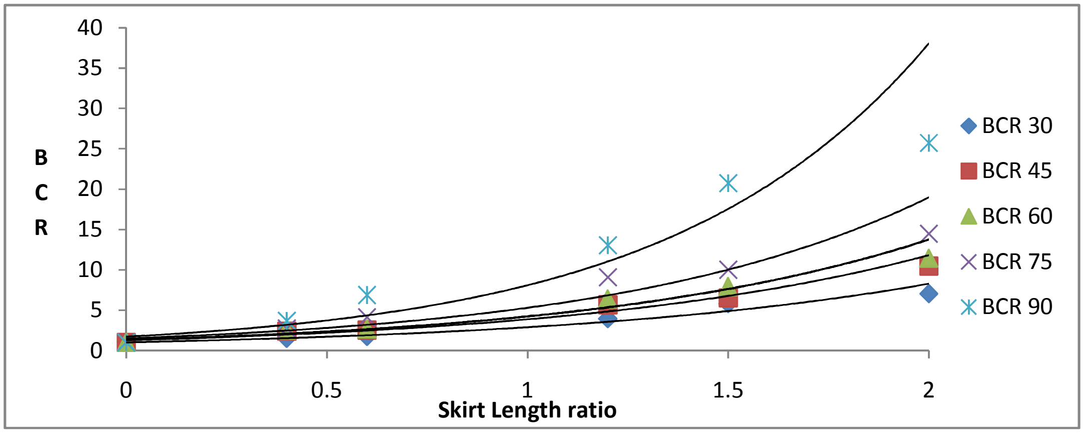
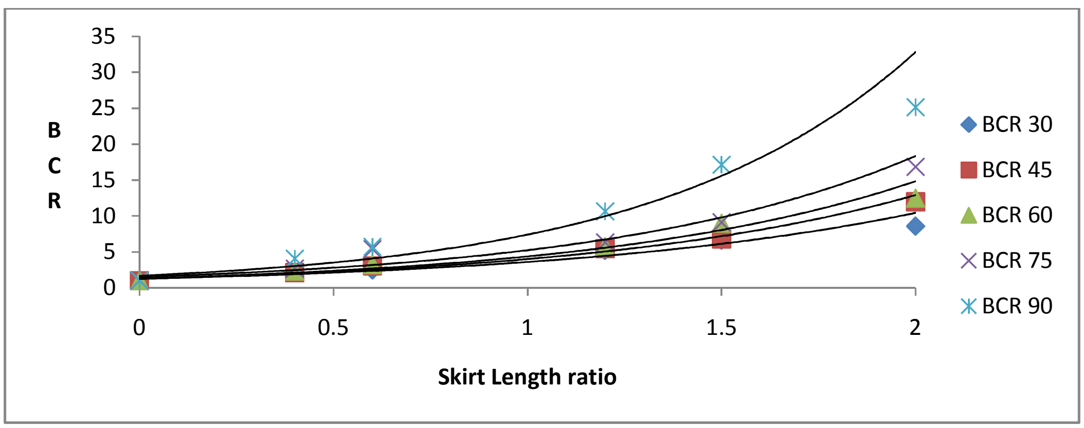


Fig.4.12. Variation of BCR with smooth skirt ratio for 60 mm dia. footing.



.Fig.4.13.Variation of BCR with rough skirt ratio for 60 mm dia. footing.

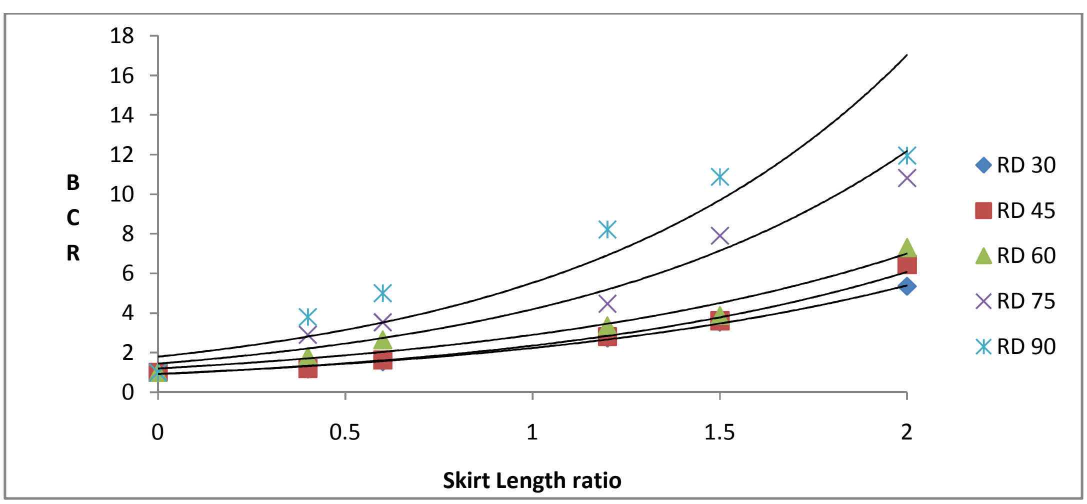


Fig.4.14 Variation of BCR with smooth skirt ratio for 40 mm dia. footing.

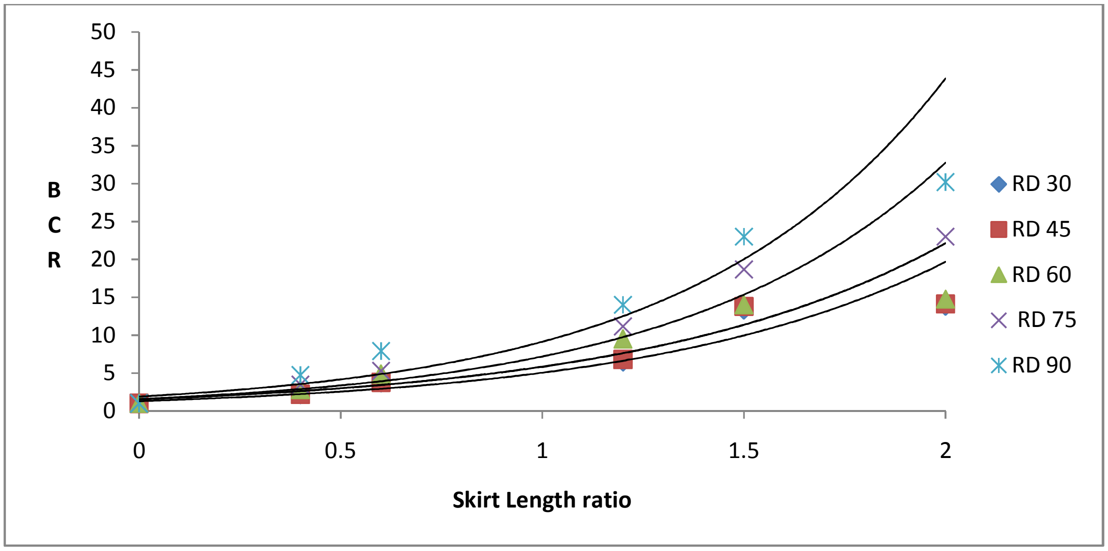


Fig.4.15 Variation of BCR with smooth skirt ratio for 100 mm dia. footing.

The variation of BCR is plotted against L/D ratio for footings of 40 mm, and 100 mm in Figs. 4.14 and 4.15 respectively. The BCR increases with increase in skirt length almost parabolically. The rate of increase in bearing capacity with skirt ratio is not same for all size of footings embedded in sand of different relative densities. The increase in BCR with skirt ratio is higher for footings at larger dia. with higher relative density. So it can be concluded that the improvement of bearing capacity is a function of skirt length, diameter and also depends on the relative density of sand bed in which it is embedded.The variation of BCR is plotted against L/D ratio for embedded solid footings of diameter 60mm for smooth and rough condition in Figs.4.16 and 4.17 respectively. From the both figure it has similarity that at higher density and at higher density the bearing capacity is 28 times and all the values are nearly equal. The results of the skirted foundations exhibit bearing capacity and settlement values that are close, but not equal, to those of solid foundations of the same width and depth.

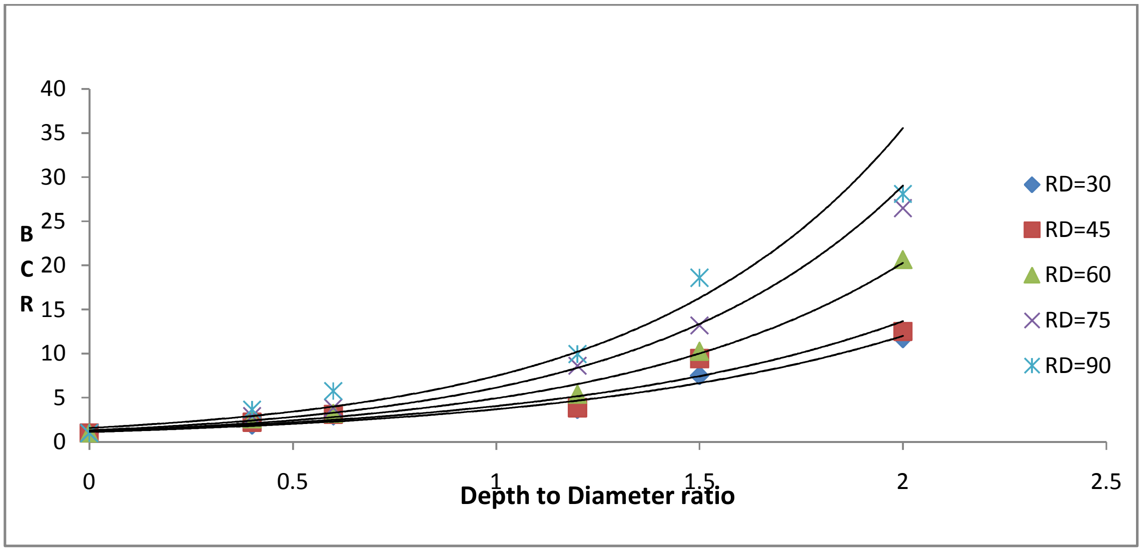


Fig.4.16 Variation of BCR with depth ratio for 60 mm dia. for smooth solid footing.

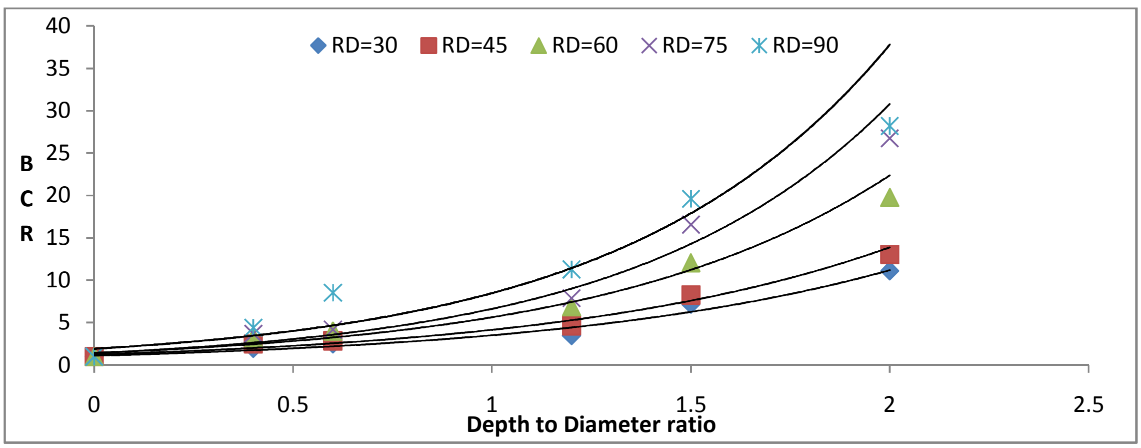


Fig4.17 Variation of BCR with depth ratio for 60 mm dia. for rough solid footing.

4.2.3Effects of relative density on bearing capacity

The bearing capacity ratio BCR is defined as the ratio of bearing capacity of skirt footing to bearing capacity of surface footing at similar testing conditions. Figs.4.18 and 4.19show the variation of BCR with relative density of sand bed for smooth and rough footings respectively. These curves show an exponential increase of BCR with relative density of sand both for smooth and rough footings. The increase in bearing capacity ratio with relative density of sand may be attributed to the increase in angle of internal friction value of soil, which mainly occurs to additional inter locking between particles in a denser state. Though the absolute bearing capacity values of a rough footing is higher compared to smooth footing at comparable conditions. But it is observed that both for smooth and rough skirt footings the bearing capacity ratio at a given skirt ratio or relative density of embedded sand is found to be more or less equal. For both smooth and rough footings at L/D=2 the bearing capacity ratio is 25 times more than surface footing embedded in a sand bed with a relative density of 90%..

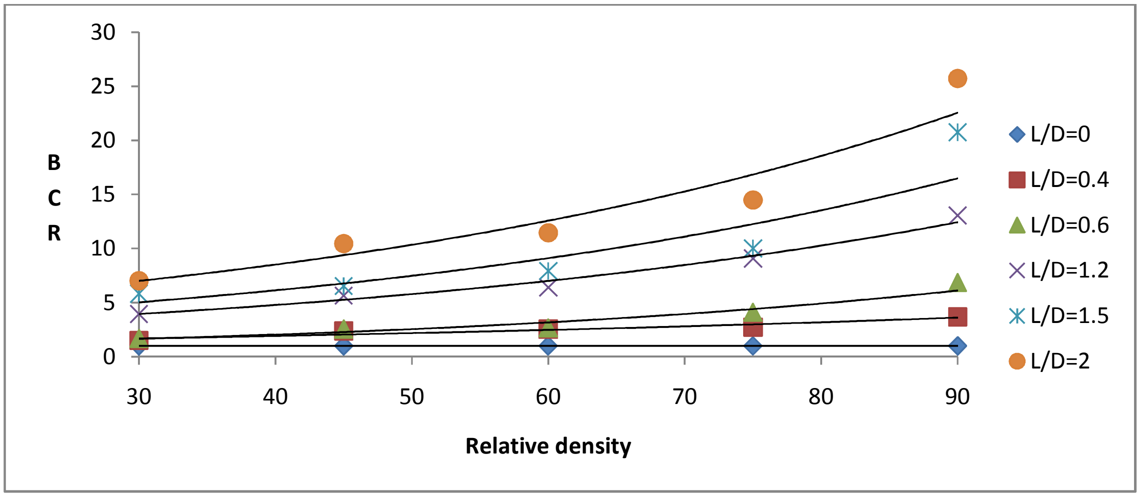


Fig4.18 Variation of BCR with relative density for 60 mm dia. for smooth skirt footing.

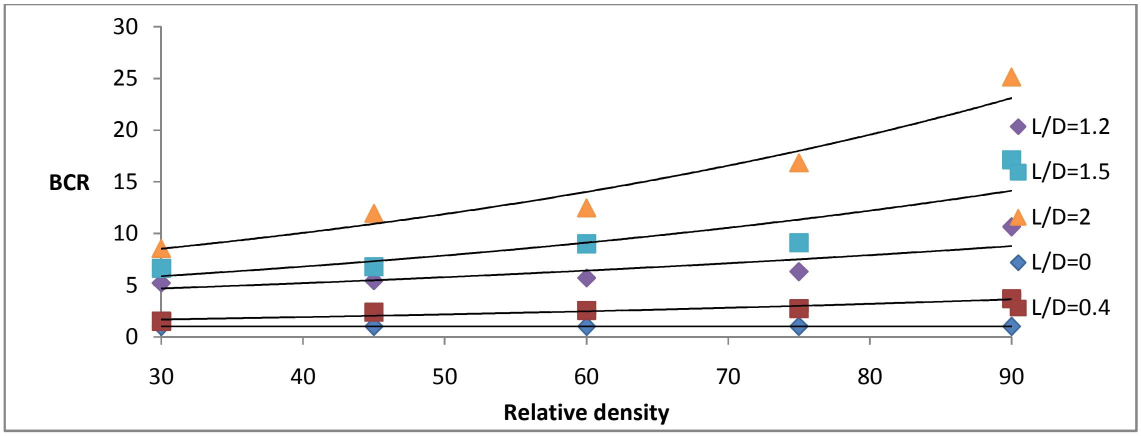


Fig4.19Variation of BCR with relative density for 60 mm dia. for rough skirt footing.

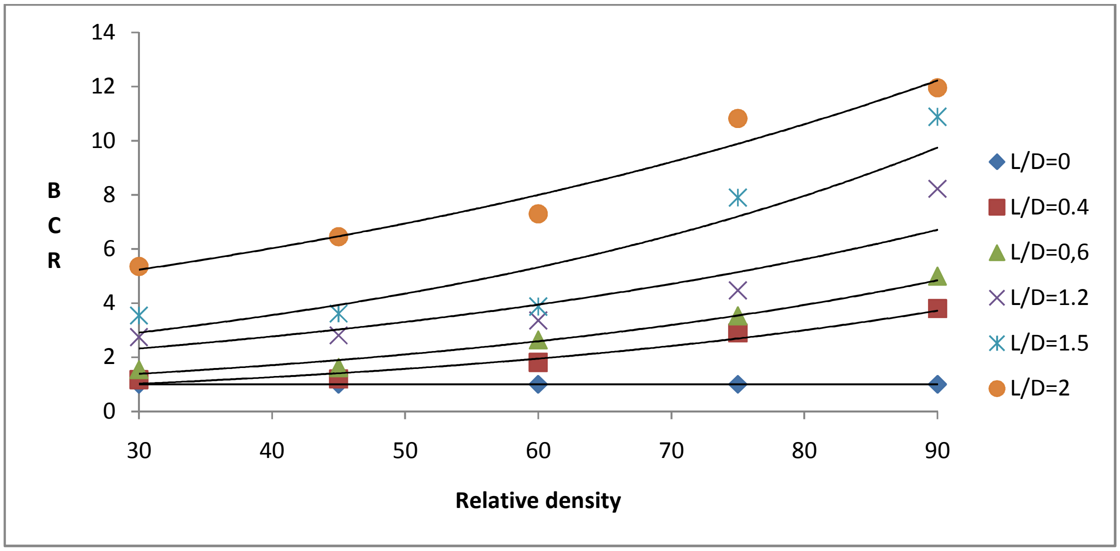


Fig4.20 Variation of BCR with relative density for 40 mm dia. for skirt footing.

Figs.4.19 and 4.20 show the variation of BCR with relative density of sand bed for 40mm and 100mm for skirt footings respectively. For footings of 40 mm dia. at L/D=1.5, the bearing capacity ratio is 8 times, in 60 mm dia. there is increase of 10 times and for 100mm diameter there is increase of 11.2 times more than surface footing embedded in a sand bed with a relative density of 75%. For footings of 40 mm dia. at L/D=2 the bearing capacity ratio is 12 times, in 60 mm dia. there is increase of 25 times and for 100mm diameter there is increase of 25 times more than surface footing embedded in a sand bed with a relative density of 90%.Figs.4.22 and 4.23 show the variation of BCR with relative density of sand bed for 60mm both for smooth and rough embedded footings respectively.

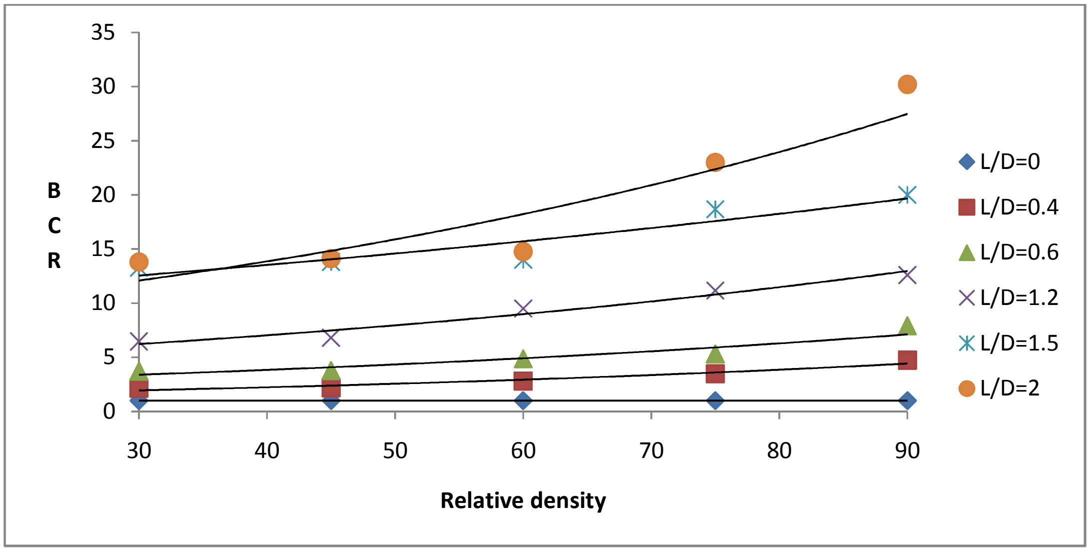


Fig4.21 Variation of BCR with relative density for 100 mm dia. for skirt footing

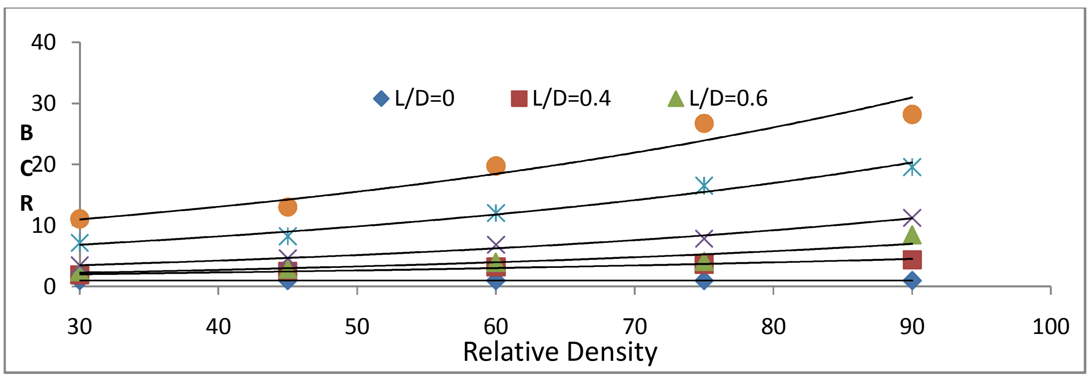


Fig4.22 Variation of BCR with relative density for 60 mm dia. for smooth solid footing

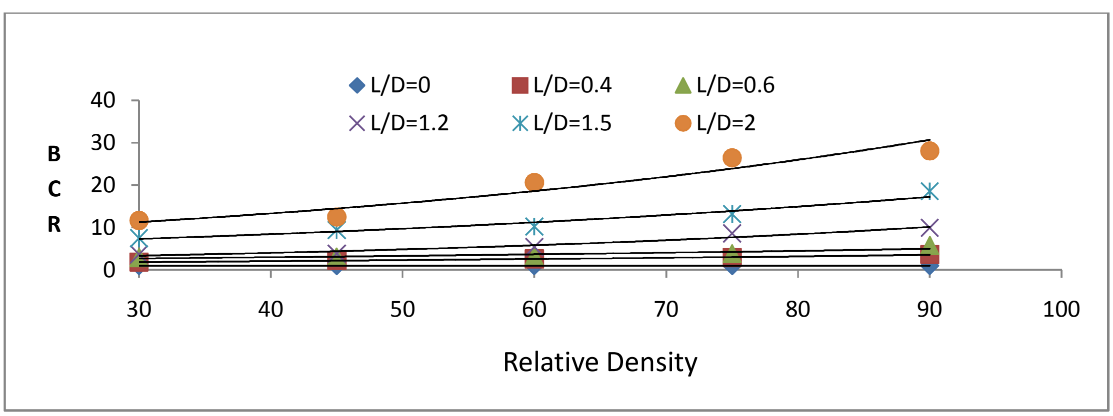


Fig4.23 Variation of BCR with relative density for 60 mm dia. for rough solid footing.

4.2.4Effects of angle of internal friction on bearing capacity

The variation of bearing capacity ratio (BCR) is plotted against angle of internal friction for smooth and rough footings for 60 mm dia. in Fig 4.24 and 4.25 respectively. Trend lines are drawn to know the relationship between them. The angle of internal friction (Φ) has determined from shear test. BCR has plotted with different Φ values of the sand bed. In this case, also a similar type of relationship observed as is observed in case of BCR with relative density. This is obvious as the angle of internal friction value of the sand bed is a function of relative density of sand. The increase in BCR is found to be more with footing having higher angle of internal friction. The variation of bearing capacity ratio (BCR) is plotted against angle of internal friction for 40 mm dia. and 10 mm dia.footings in Fig 4.26 and 4.27 respectively.

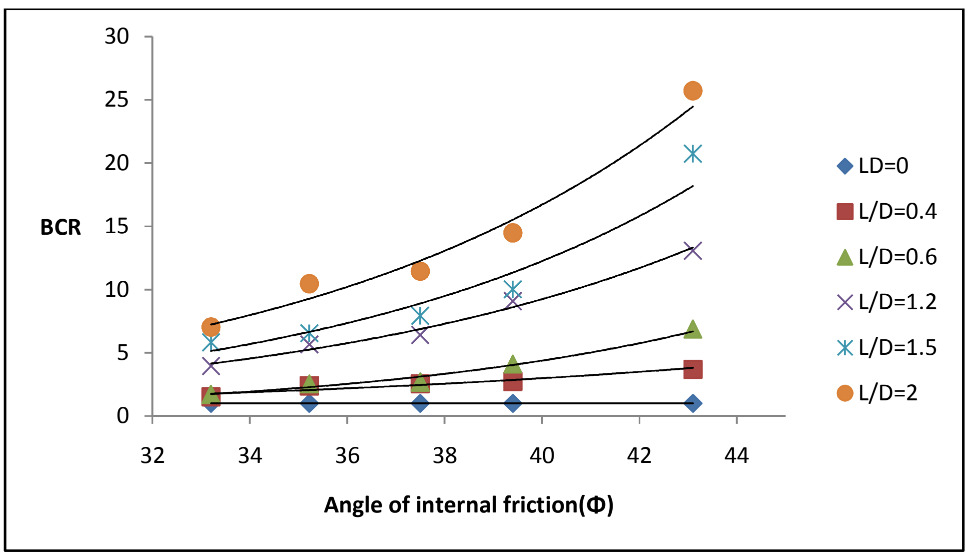


Fig. 4.24 Variation of bearing capacity ratio with angle of internal friction for smooth footings for 60mm

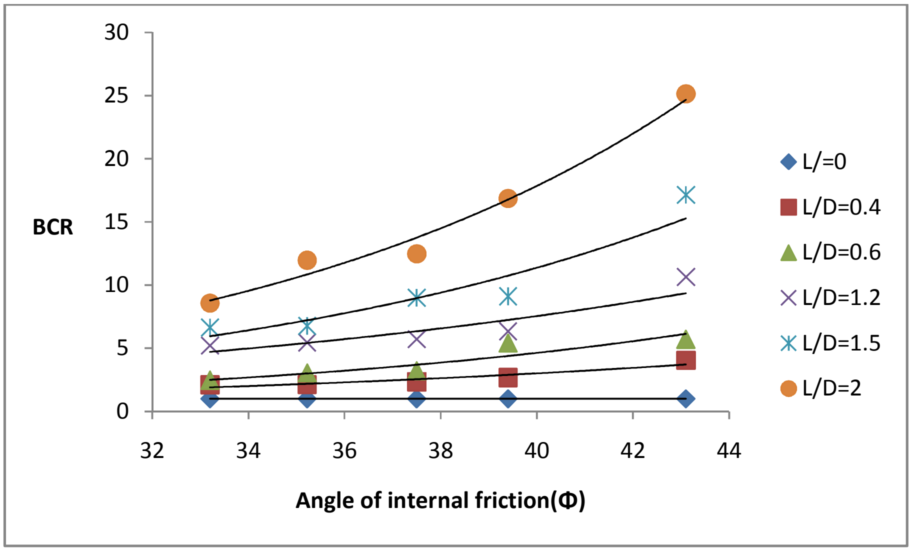


Fig. 4.25 Variation of bearing capacity ratio with angle of internal friction for rough footings for 60mm

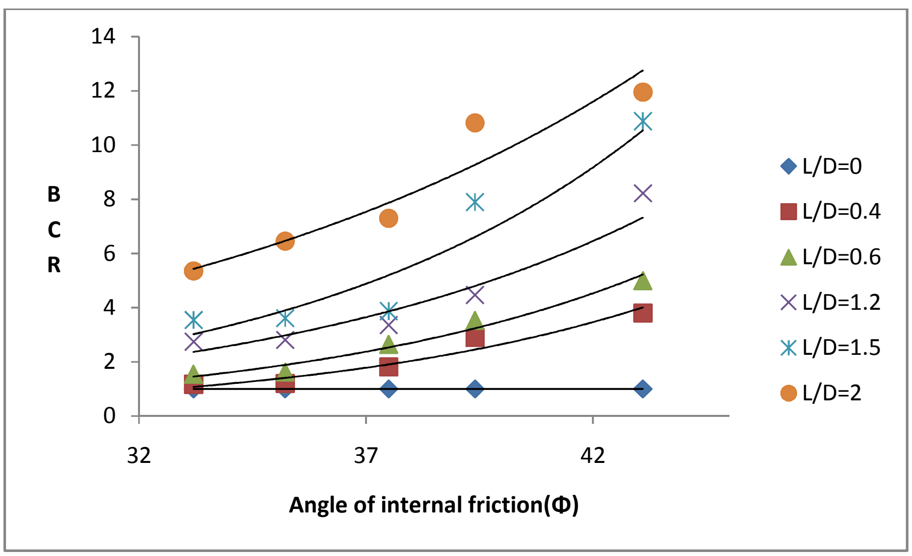


Fig.4.26 Variation of bearing capacity ratio with angle of internal friction for 40mm dia. footings

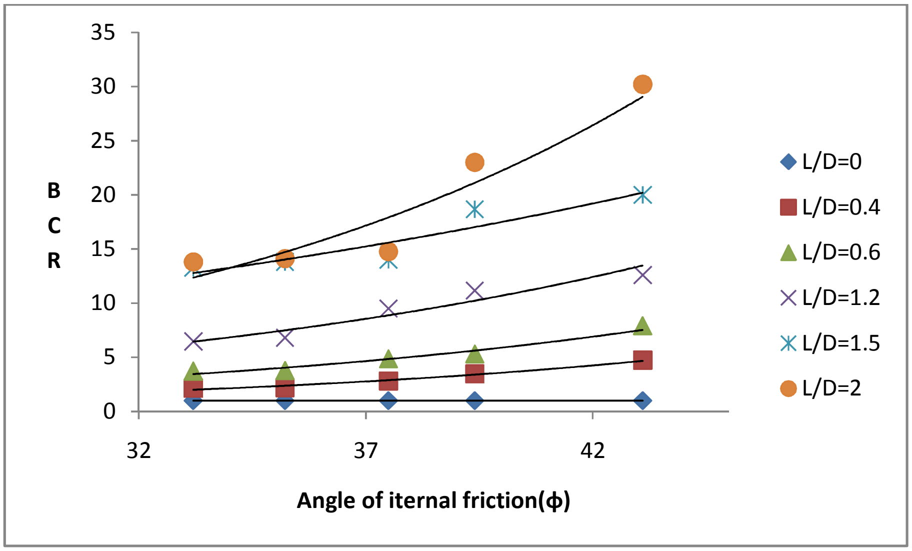


Fig.4.27 Variation of bearing capacity ratio with angle of internal friction for 100mm dia. footings**.**

4.2.5 Effects of footing size on bearing capacity

BCR has been plotted against the size of footing at constant relative density and is shown in 4.28, 4.29 and 4.30. It observed that when the dia. of the footing increases the unit bearing pressure also increases. For the lower relative density 30% at L/D=2 it observe that BCR is 2.6 times more in 100mm dia. comparing to 40mm dia.at higher density 75% of same L/D ratio the BCR increases 2.12 times.

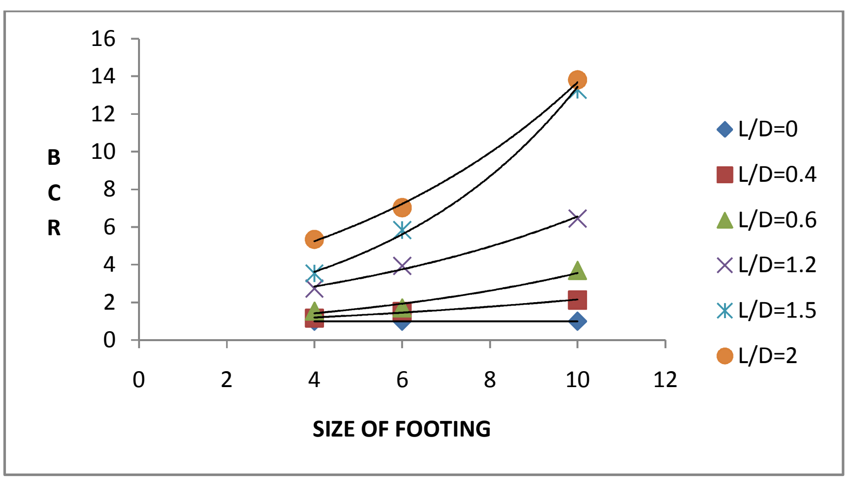


Fig. 4.28 Variation of BCR with diameter of footing at Relative Density 30%

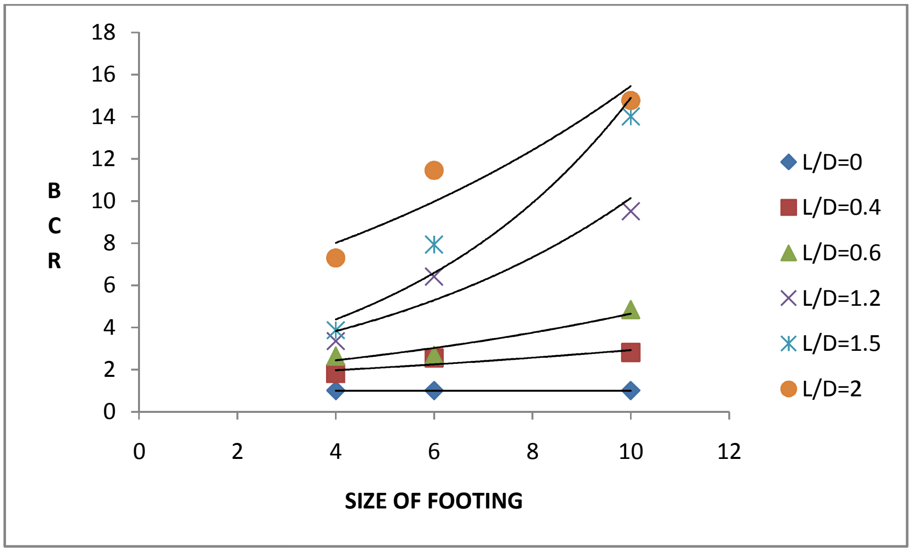


Fig. 4.29Variation of BCR with diameter of footing at Relative Density 60%

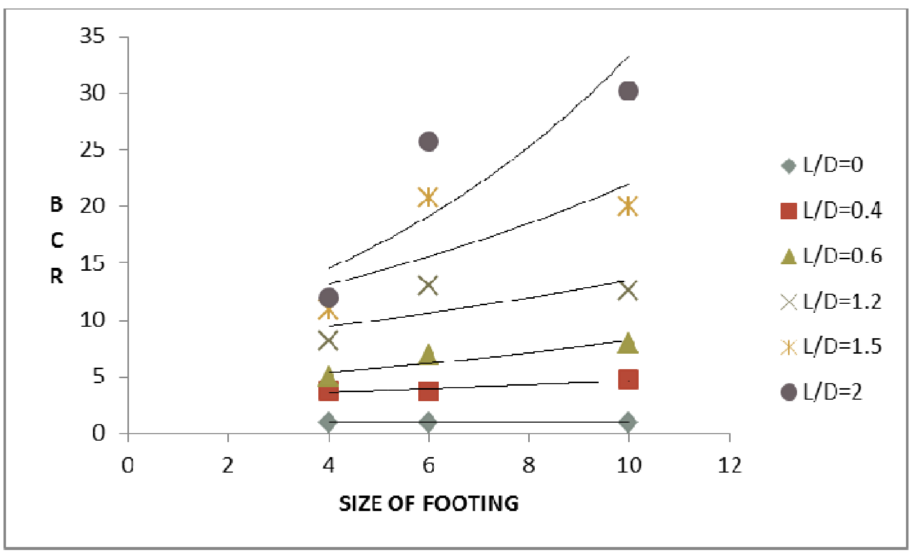


Fig. 4.30Variation of BCR with diameter of footing at Relative Density 90%

4.3COMPARISION OF EXPERIMENTAL RESULTS WITH HANSEN AND MEYRHOF

(IS :6403-1981) recommends the bearing capacity equation which is similar in nature given by Meyerhof and Brinch Hansen. For length to diameter ratio L/D 0.4, 0.6 it has considered as shallow footings. Length is greater then the diameter it is considered as deep foundation for 1.2, 1.5 and 2. Comparing the theoretical results with experimental it can observe that the value of experimental results are nearly equal to Meyerhof. (Please refer figures 4. 31 to 4. 35). The results of Hansen are much higher from experimental results.

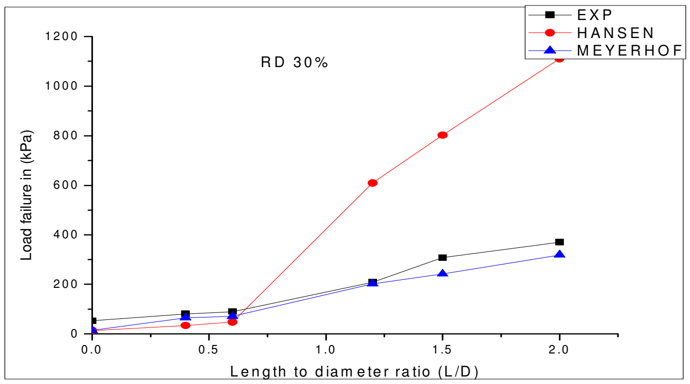


Fig. 4.31Comparison of experimental results at relative density 30%

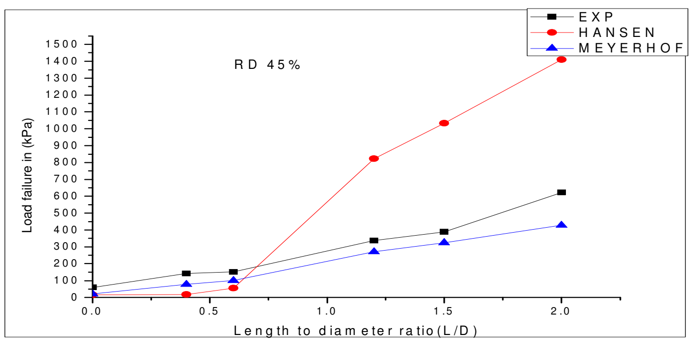


Fig. 4.32 Comparison of experimental results at relative density45%

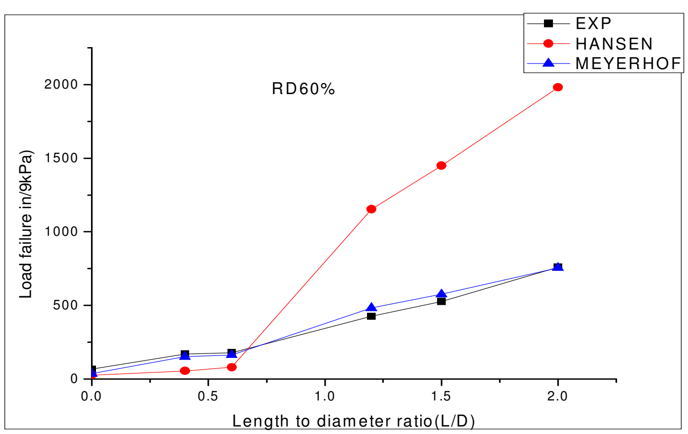


Fig. 4.33 Comparison of experimental results at relative density60%

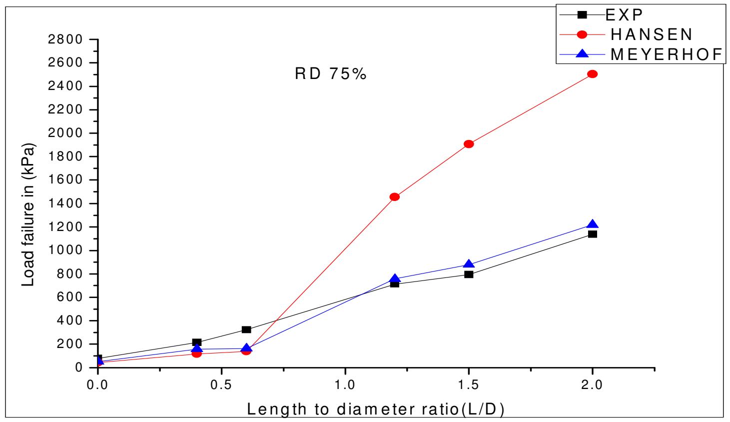


Fig. 4.34 Comparison of experimental results at relative density75%

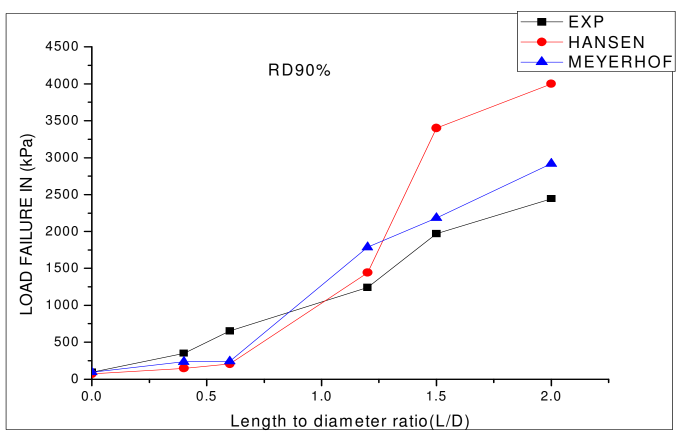


Fig. 4.35 Comparison of experimental results at relative density90%

4.4HORIZONTAL LOADING

4.4.1Load-Settlement Behaviour

Typical load-settlement curves for circular skirted footing with skirt of 60mm are shown in Fig.4.35, 4.36, 4.37, 4.38and 4.39.for L/D ratio 0.4, 0.6, 1.2, 1.5and 2 respectively.. Analysis of the experimental results revealed that increase in length of skirts improves the lateral capacity of the skirted foundations on sand. The improvement in magnitude increases with increasing the skirt depth as well as relative density. At higher relative density the stress reaches to a peak value at low strain and sudden failure occurs. But at lower relative density the stress reaches to peak value at high strain and sudden failure occurs. Further it is noticed that the stiffness of load-settlement curves increases with increase in skirt ratio(figure 4.40) and relative density.

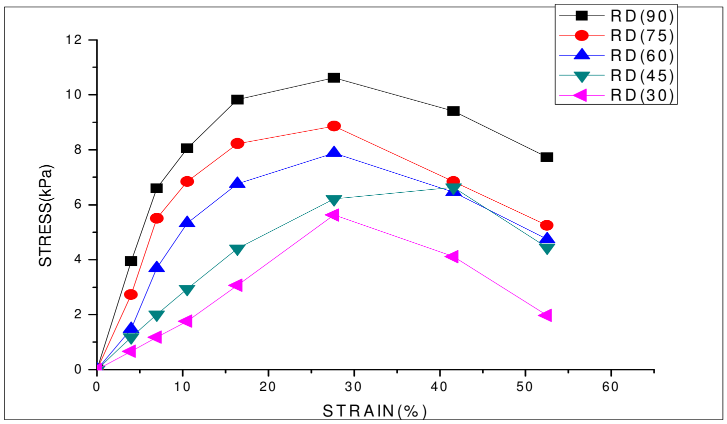


Fig.4.36Stress-strain behaviour ofskirted footingof 60mm dia. at L/D Ratio 0.4

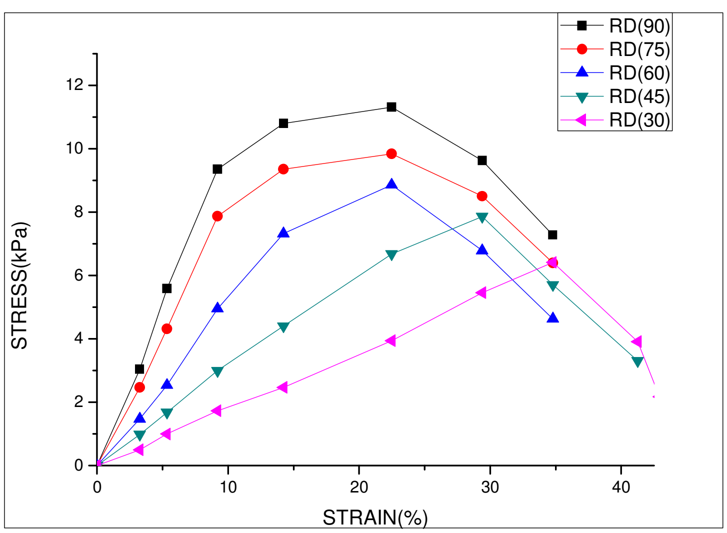


Fig.4.37Stress-strain behaviour ofskirted footingof 60mm dia. at L/D Ratio 0.6

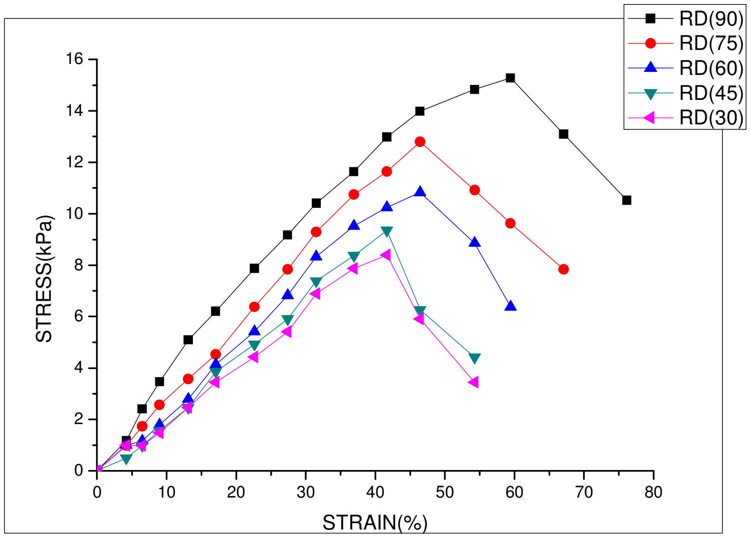


Fig.4.38Stress-strain behaviour ofskirted footingof 60mm dia. at L/D Ratio 1.2

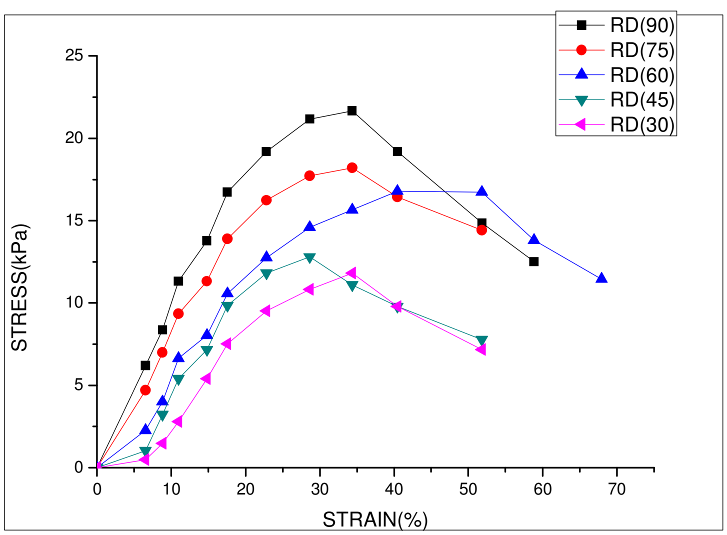


Fig.4.39Stress-strain behaviour ofskirted footingof 60mm dia. at L/D Ratio 1.5

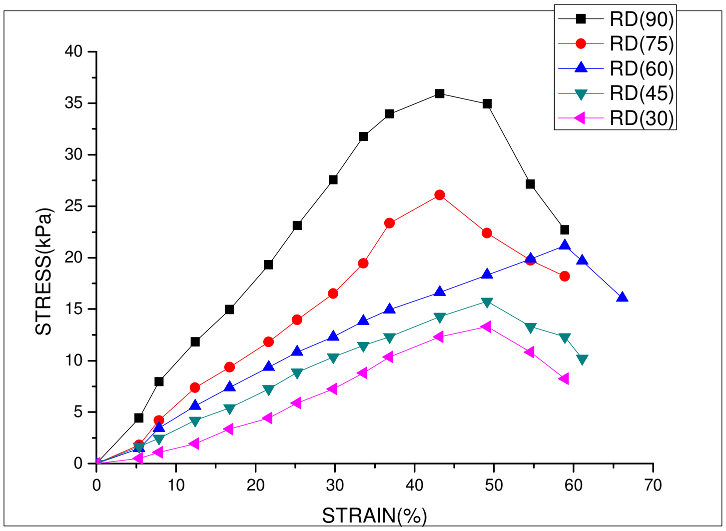


Fig.4.40Stress-strain behaviour of skirted footingof 60mm dia. at L/D Ratio 2

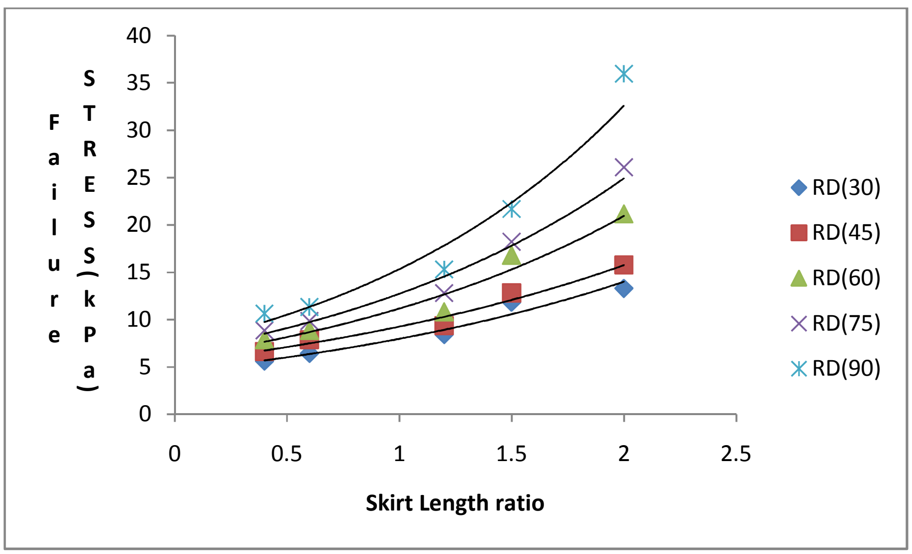


Fig.4.41Horizontal Failure Load with Skirt Length Ratio.

CHAPTER 5

CONCLUSION

CONCLUSION

The performance of a circular footing with a structural skirt resting on sand and subjected to a vertical load and horizontal load is investigatedthrough an experimental study. A series of tests were conducted in a model test tank to evaluate the performance in terms of improvement in bearing capacity and reduction in settlement of a circular footing with and without a structural skirt. From the results and discussion presented above, the following conclusions are drawn:

1) Skirt factors are proposed which can be introduced into the general ultimate bearing capacity equation to estimate the bearing capacity of a circular footing resting on sand. The predictions made through the modified equation are in good agreement with the experimental results.

(2) A structural skirt increases the bearing capacity, reduces the settlement and modifies the load settlement behaviour of the footing.

(3) The bearing capacity of a circular footing is increased in the range 11.2 to 30% and is dependent on the geometrical and surface properties of the skirt, characteristics of sand bed.

(4)The data and interpretations presented in the study showed that the ultimate bearing capacity increases with the size of the footing, the length of skirts and the relative density of sand. However, the failure strain is found to increase with the size of the footings and skirt length but decreases with increase in relative density of sand bed. Prototype field tests are needed to validate the findings of these experimental results

(5) The data and interpretations presented in the study showed that BCR ratio increases when the relative density increases. The BCR increases with either increase in the L/D ratio and/or angle of internal friction. The results of this study revealed that smooth skirted foundationsskirted foundations exhibit bearing capacity and settlement values at failure lesser then rough skirted foundations at similar conditions

SCOPE OF FUTURE STUDY

- Vertical load test of different skirt length in submerged condition
- Vertical load test in saturated condition
- Horizontal load test in change in dia. and change in skirt length
- Horizontal load test in saturated condition.
- Numerical analysis and finite element analysis has to be done for different skirt length and change in skirt diameter.

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